IN-LB	Inch-Pound Units
SI	International System of Units

An ACI Standard

Code Requirements for Seismic Analysis and Design of Liquid-Containing Concrete Structures (ACI 350.3-20) and Commentary

Reported by ACI Committee 350

ACI 350.3-20

--`,,```,,,`,,`,,`,,`,,,,`,,`-`-`,,`,,`,`,,`---

American Concrete Institute
Always advancing

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Not for Resale, 01/16/2022 21:33:25 MST
Encuentra más documentos en www.udocz.com

First Printing
October 2021
ISBN: 978-1-64195-161-6

Code Requirements for Seismic Analysis and Design of Liquid-Containing Concrete Structures (ACI 350.3-20) and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at http://concrete.org/Publications/DocumentErrata.aspx. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided "as is" without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised the ACI Collection of Concrete Codes, Specifications, and Practices.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

--`,,```,,,,````-`-`,,`,,`,`,,`---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Not for Resale, 01/16/2022 21:33:25 MST
Encuentra más documentos en www.udocz.com

ACI 350.3-20

Code Requirements for Seismic Analysis and Design of Liquid-Containing Concrete Structures (ACI 350.3-20) and Commentary

An ACI Standard

Reported by Joint ACI Committee 350

M. Reza Kianoush,* Chair — Jon B. Ardahl, Vice Chair — Andrew R. Minogue,‡ Secretary

Iyad M. Alsamsam
John W. Baker
Chuen-Shiow Chen*
Steven R. Close*
Mark W. Cunningham
Robert E. Doyle
Ronald R. Fiore
Anthony J. Galterio*
Carl A. Gentry*
Kenneth Ryan Harvey
Keith W. Jacobson
Edwina S. Lui
Daniel J. McCarthy
Kevin H. Monroe*
Khalid Motiwala
Jerry Parnes
Risto Protic*
Satish K. Sachdev
William C. Sherman†
Manwendra Sinha
Pericles C. Stivaros
Shashiprakash G. Surali
Lawrence M. Tabat*
John M. Tehaney*
Miroslav Vejvoda
William A. Wallace
Jeffrey S. Ward

Subcommittee Members

Ahmed Hafez
Atis A. Liepins
Sanjay S. Mehta
Rolf P. Pawski
Nazar Sabti

Consulting Members

William H. Backouse
Patrick J. Creegan
Anthony L. Felder
Charles S. Hanskat
Jerry A. Holland
David G. Kittridge
Dennis C. Kohl
Nicholas A. Legatos
Kyle S. Loyd
Carl H. Moon
Lawrence G. Mrazek
Javeed Munshi
Terry Patzias
Andrew R. Philip
Narayan M. Prachand
David M. Rogowsky
Lawrence J. Valentine

*Members of Seismic Provisions Subcommittee.

†Seismic Provisions Subcommittee Chair.

‡Seismic Provisions Subcommittee Secretary.

This Code prescribes procedures for the seismic analysis and design of liquid-containing concrete structures. These procedures address the loading side of seismic design and are intended to complement Section 1.1.9 and Chapter 13 of ACI 350-20.

Keywords: circular tanks; concrete tanks; convective component; earthquake resistance; environmental concrete structures; impulsive component; liquid-containing structures; rectangular tanks; seismic resistance; sloshing; storage tanks.

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

ACI 350.3R-20 supersedes 350.3-06, became effective November 20, 2020, and was published October 2021.

Copyright © 2021, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Not for Resale, 01/16/2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

PREFACE

From the time it embarked on the task of developing an ACI 318-dependent code, ACI Committee 350 decided to expand on and supplement the seismic provisions for "Special Provisions for Seismic Design" to provide a set of thorough and comprehensive procedures for the seismic analysis and design of commonly used types of liquid-containing structures of circular and rectangular configurations. The committee's decision was influenced by the recognition that liquid-containing structures are unique structures whose seismic design is not adequately covered by the leading national codes and standards. A seismic design subcommittee was appointed with the charge to implement the committee's decision.

The seismic subcommittee's work was guided by two main objectives:

(1) Produce a self-contained set of procedures that would enable a practicing engineer to perform a full seismic analysis and design of a liquid-containing structure. These procedures should cover both aspects of seismic design: the "loading side," which is the determination of the seismic loads based on the mapped risk-adjusted maximum considered earthquake spectral response accelerations at short periods (S_s) and 1 second (S_1) obtained from the Seismic Ground Motion maps (ASCE/SEI 7-16 Chapter 22) and the geometry of the structure; and the "resistance side," which is the detailed design of the structure in accordance with the provisions of ACI 350-20, to resist those loads safely.

(2) Establish the scope of the new procedures consistent with the overall scope of ACI 350-20. This required the inclusion of all types of tanks—rectangular as well as circular; and reinforced concrete as well as prestressed.

There are currently at least two national standards that provide detailed procedures for the seismic analysis and design of liquid-containing structures: ANSI/AWWA D110-13 (R18), which is limited to circular, prestressed concrete tanks; and ANSI/AWWA D115-17, which covers both rectangular and circular prestressed concrete tanks.

As the loading side of seismic design is outside the scope of ACI 318, it was decided to maintain this practice in ACI 350 as well. Accordingly, the basic scope, format, and mandatory language of Chapter 21 of ACI 318-11 were retained with only enough revisions to adapt the seismic provisions to environmental engineering structures. Provisions similar to Section 1.1.9 of ACI 318-11 are included in ACI 350. This approach offers at least two advantages:

(1) Allows ACI 350 to maintain the ACI 318 practice of limiting its seismic design provisions to the resistance side only.

(2) Makes it easier to update these seismic provisions to keep up with the frequent changes and improvements in the field of seismic hazard analysis and evaluation.

The forces due to earthquake determined in accordance with this Code are intended to be used in the determination of load effects due to earthquake, E, in accordance with Chapter 9 of ACI 350-20. The seismic force levels and R-factors included in this Code provide results at strength levels, such as those included for seismic design in the International Code Council (ICC) 2012 International Building Code (IBC 2012), particularly the applicable connection provisions of IBC 2012 as referenced in ASCE/SEI 7-16. When comparing these provisions with other documents defining seismic forces at allowable stress levels (for example, the 1997 Uniform Building Code [UBC-1997]), the seismic forces in this Code should be reduced by the applicable factors to derive comparable forces at allowable stress levels.

Users should note the following general design methods used in this Code, which represent the evolution of seismic design of liquid-containing structures over a number of years since ASCE (1984), as follows:

(a) Instead of assuming a rigid tank for which the acceleration is equal to the ground acceleration at all locations, this Code assumes amplification of response due to natural frequency of the tank.

(b) The response modification factor is included.

(c) Rather than combining impulsive and convective modes by algebraic sum, this Code combines these modes by square-root-sum-of-the-squares.

(d) The effects of vertical acceleration are included.

(e) An effective mass coefficient applicable to the mass of the walls is included.

For further information on seismic behavior of liquid-containing structures, refer to Housner (1957, 1963b). For fluids other than water, refer to Veletsos and Shivakumar (1997).

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CONTENTS

PREFACE, p. 2

CHAPTER 1—GENERAL REQUIREMENTS, p. 4
1.1—Scope, p. 4
1.2—Notation, p. 4
1.3—Definitions, p. 10

CHAPTER 2—TYPES OF LIQUID-CONTAINING STRUCTURES, p. 11
2.1—Ground-supported structures, p. 11
2.2—Pedestal-mounted structures, p. 12

CHAPTER 3—GENERAL CRITERIA FOR ANALYSIS AND DESIGN, p. 13
3.1—Dynamic characteristics, p. 13
3.2—Design loads, p. 13
3.3—Design requirements, p. 13

CHAPTER 4—EARTHQUAKE DESIGN LOADS, p. 14
4.1—Earthquake pressures above base of tank wall, p. 14
4.2—Application of site-specific response spectra, p. 17

CHAPTER 5—EARTHQUAKE LOAD DISTRIBUTION, p. 19
5.1—General, p. 19
5.2—Shear transfer, p. 19
5.3—Dynamic force distribution above base of tank wall, p. 21

CHAPTER 6—STRESSES, p. 26
6.1—Rectangular tanks, p. 26
6.2—Circular tanks, p. 26

CHAPTER 7—FREEBOARD, p. 27
7.1—Wave oscillation, p. 27

CHAPTER 8–EARTHQUAKE-INDUCED EARTH PRESSURES, p. 32
8.1—General, p. 32
8.2—Limitations, p. 33
8.3—Alternative methods, p. 33

CHAPTER 9—DYNAMIC MODEL, p. 34
9.1—General, p. 34
9.2—Rectangular tanks (Type 1), p. 36
9.3—Circular tanks (Type 2), p. 40
9.4—Seismic response coefficients C_i, C_c, and C_t, p. 44
9.5—Site-specific seismic response coefficients C_i, C_c, and C_t, p. 45
9.6—Effective mass coefficient ε, p. 46
9.7—Pedestal-mounted tanks, p. 46

CHAPTER 10—COMMENTARY REFERENCES, p. 47

APPENDIX A—DESIGN METHOD, p. 49
A.1—General outline of design method, p. 49

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials - www.concrete.org
Wednesday, January 19, 2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

CODE

CHAPTER 1—GENERAL REQUIREMENTS

1.1—Scope

This Code describes procedures for the design of liquid-containing concrete structures subjected to seismic loads. These procedures shall be used in accordance with Chapter 13 of ACI 350-20.

1.2—Notation

A_s = cross-sectional area of prestressed and non-prestressed steel reinforcement, in.^{2} (mm^2)

b = ratio of vertical to horizontal design acceleration

B = inside dimension (length or width) of a rectangular tank, perpendicular to the direction of the ground motion being investigated, ft (m)

C_c, C_i, and C_t = period-dependent seismic response coefficients (9.4, 9.5)

C_l, C_w = coefficients for determining the fundamental frequency of the tank-liquid system (Eq. (9.3.4b) and Fig. 9.3.4b)

C_s = period-dependent seismic coefficient

d_{max} = maximum vertical displacement of an oscillating wave measured from the liquid surface at rest, ft (m)

D = inside diameter of circular tank, ft (m)

EBP = excluding base pressure (datum line just above the base of the tank wall)

COMMENTARY

CHAPTER R1—GENERAL REQUIREMENTS

R1.1—Scope

This Code is a companion Code to Chapter 13 of the American Concrete Institute, "Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary (ACI 350R-20)."

This Code provides requirements for the designer of liquid-containing concrete structures for computing seismic forces that are to be applied to the particular structure. The designer should also consider the effects of seismic forces on components outside the scope of this Code, such as piping, equipment (for example, clarifier mechanisms) and connecting walkways where vertical or horizontal movements between adjoining structures or surrounding backfill could adversely influence the ability of the structure to function properly (NSF 1981). Moreover, seismic forces applied at the interface of piping or walkways with the structure may also introduce appreciable flexural or shear stresses at these connections.

The hydrodynamic forces described in ACI 350.3 can be used in design of liquid-containing concrete structures other than environmental structures if the licensed design professional or another reference standard chooses to use or refer to it.

The operational conditions used to calculate the seismic forces determined by this Code need to be evaluated by the licensed design professional. Considerations such as normal operational liquid levels, and potential for a tank or cells within a tank to be empty during a seismic event should be included. It is common to consider several loading conditions when designing for seismic loading, such as with the liquid at normal operating levels and with the tank or individual tank cells empty.

R1.2—Notation

For C_s, refer to ASCE/SEI 7-16 Section 12.8.1.

EBP refers to the hydrodynamic design in which it is necessary to compute the overturning of the wall with respect to the top of the tank floor, excluding base pressure (that is, excluding the pressure on the floor itself). EBP

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

E_c = modulus of elasticity of concrete, psi (MPa)
E_s = modulus of elasticity of cable, wire, strand, or conventional reinforcement, psi (MPa)
F_a = short-period site coefficient (at 0.2 second period) from ASCE/SEI 7-16 Table 11.4-1
F_v = long-period site coefficient (at 1.0 second period) from ASCE 7-16, Table 11.4-2
G_p = shear modulus of elastomeric bearing pad, psi (MPa)
G = acceleration due to gravity (32.17 ft/s^2 [9.807 m/s^2])
h_c = height above the base of the tank wall to the center of gravity of the convective lateral force for the case excluding base pressure (EBP), ft (m)
h_c' = height above the base of the tank wall to the center of gravity of the convective lateral force for the case including base pressure (IBP), ft (m)
h_{eg} = height above the base of the tank wall to the center of gravity of the lateral force due to the dynamic earth pressure, and from saturated and unsaturated soils, ft (m)
h_i = height above the base of the tank wall to the center of gravity of the impulsive lateral force for the case excluding base pressure (EBP), ft (m)
h_i' = height above the base of the tank wall to the center of gravity of the impulsive lateral force for the case including base pressure (IBP), ft (m)
h_r = height from the base of the tank wall to the center of gravity of the tank roof, ft (m)
h_w = height from the base of the tank wall to the center of gravity of the tank shell, ft (m)
H_L = design depth of stored liquid, ft (m)
H_w = wall height above top of floor (inside dimension), ft (m)
I = importance factor, from Table 4.1.1a
I_b = moment of inertia at the base of the tank
IBP = including base pressure (datum line at the base of the tank wall including the effects on the tank bottom including dynamic fluid pressure on the tank bottom)

COMMENTARY

hydrodynamic design is used to determine the need for hold-downs in non-fixed base tanks. EBP is also used in determining the design pressure acting on walls. (For explanation, refer to Housner [1963a].)

H = as defined in Section R9.2.4, ft (m)

IBP refers to the hydrodynamic design in which it is necessary to investigate the overturning of the entire structure with respect to the tank support foundation. IBP hydrodynamic design is used to determine the design pressure acting on the tank floor and the underlying foundation. This pressure is transferred directly either to the subgrade or to other supporting structural elements. IBP accounts for moment effects due to dynamic fluid pressures on the bottom of the tank by increasing the effective vertical moment arm to the applied lateral forces. (For explanation, refer to Housner [1963a].)

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

k_a = spring constant of the tank wall system, lb/ft per foot of wall width (N/m per meter of wall width)

K = flexural stiffness of a unit width of a rectilinear tank wall, lb/ft per foot of wall width (N/m per meter of wall width)

K_a = active coefficient of lateral earth pressure

K_o = coefficient of lateral earth pressure at rest

L = inside dimension of a rectangular tank, parallel to the direction of the ground motion being investigated, ft (m)

L_c = effective length of restraint cable taken as the sleeve length plus 35 times the cable diameter, in. (mm)

L_p = length of individual elastomeric bearing pads, in. (mm)

m_i = impulsive mass of contained liquid per unit width of a rectangular tank wall, lb-s^2/ft per foot of wall width (kg per meter of wall width)

m_w = mass per unit width of a rectangular tank wall, lb-s^2/ft per foot of wall width (kg per meter of wall width)

M = total mass per unit width of a rectangular wall = $m_i + m_w$, lb-s^2/ft per foot of wall width (kg per meter of wall width)

M_b = bending moment on the entire tank cross section just above the base of the tank wall, ft-lb (kN-m)

M_c = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the convective force P_c, ft-lb (kN-m)

M_c' = overturning moment at the base of the tank wall, including dynamic fluid pressure on the tank bottom (IBP), due to the convective force P_c, ft-lb (kN-m)

M_{eg} = bending moment of the entire tank cross section just above the base of the tank wall due to dynamic earth pressure and from saturated and unsaturated soils, ft-lb (kN-m)

M_i = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the impulsive force P_i, ft-lb (kN-m)

M_i' = overturning moment at the base of the tank wall, including dynamic fluid pressure on the tank bottom (IBP), due to the impulsive force P_i, ft-lb (kN-m)

M_o = overturning moment at the base of the tank wall, including dynamic fluid pressure on the tank bottom (IBP), ft-lb (kN-m)

M_r = bending moment of the entire tank cross section just above the base of the tank wall

COMMENTARY

k_{hw} = ratio of the saturated unit weight of the backfill to the buoyant unit weight of the backfill ($k_{hw} = \gamma_s/\gamma_b$], lb/ft^3

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

(EBP) due to the roof inertia force P_r, ft-lb (kN-m)

M_w = bending moment of the entire tank cross section just above the base of the tank wall (EBP) due to the wall inertia force P_w, ft-lb (kN-m)

N_{cy} = in circular tanks, hoop force at liquid level y, due to the convective component of the accelerating liquid, lb per foot of wall height (kN/m)

N_{hy} = in circular tanks, hydrodynamic hoop force at liquid level y, due to the effect of vertical acceleration, lb per foot of wall height (kN/m)

N_{iy} = in circular tanks, hoop force at liquid level y, due to the impulsive component of the accelerating liquid, lb per foot of wall height (kN/m)

N_{wy} = in circular tanks, hoop force at liquid level y, due to the inertia force of the accelerating wall mass, lb per foot of wall height (kN/m)

N_y = in circular tanks, total effective hoop force at liquid level y, lb per foot of wall height (kN/m)

p_{vy} = unit hydrodynamic pressure due to the effect of vertical acceleration, at liquid level y, above the base of the tank wall ($p_{vy} = \ddot{u}_v \times q_{hy}$), lb/ft^2 (kPa)

P_c = total lateral convective force associated with W_c, lb (kN)

P_{cy} = lateral convective force due to W_c, per unit height of the tank wall, occurring at liquid level y, lb per foot of wall height (kN/m)

P_{eg} = lateral force on the buried portion of a tank wall due to the dynamic earth pressure and from saturated and unsaturated soils, lb (kN)

P_h = total hydrostatic force occurring on length B of a rectangular tank or diameter D of a circular tank, lb (kN)

P_{hy} = lateral hydrostatic force per unit height of the tank wall, occurring at liquid level y, lb per foot of wall height (kN/m)

P_i = total lateral impulsive force associated with W_i, lb (kN)

COMMENTARY

p_{cy} = unit lateral dynamic convective pressure distributed horizontally at liquid level y, lb/ft^2 (kPa)

p_{iy} = unit lateral dynamic impulsive pressure distributed horizontally at liquid level y, lb/ft^2 (kPa)

p_{wy} = unit lateral inertia force due to wall dead weight, distributed horizontally at liquid level y, lb/ft^2 (kPa)

For a schematic representation of P_h, refer to Fig. R5.3.1.

--``,,```,,,`,,`,,,,,,`,`,,`,,,,,,,,-`-`,,`,,`,`,,`,`---
Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials - Not for Resale, Reproduction, or Networking Permitted without license from IHS
Not for Resale, 01/03/2022 21:33:25 MST
Encuentra más documentos en www.udocz.com

CODE

P_{iy} = lateral impulsive force due to W_i, per unit height of the tank wall, occurring at liquid level y, lb per foot of wall height (kN/m)

P_r = lateral inertia force of the accelerating roof W_r, lb (kN)

P_w = lateral inertia force of the accelerating wall W_w, lb (kN)

P_w' = in a rectangular tank, lateral inertia force of one accelerating wall (W_w'), perpendicular to the direction of the earthquake force, lb (kN)

P_{wy} = lateral inertia force due to W_w, per unit height of the tank wall, occurring at level y above the base of the tank wall, lb per foot of wall height (kN/m)

P_y = combined horizontal force (due to the impulsive and convective components of the accelerating liquid; the wall's inertia, and the hydrodynamic pressure due to the vertical acceleration) at a height y above the base of the tank wall, lb per foot of wall height (kN/m)

q_{hy} = unit hydrostatic pressure at liquid level y above the base of the tank wall [$q_{hy} = \gamma_L(H_L - y)$], lb/ft^2 (kPa)

r = inside radius of circular tank, ft (m)

R = response modification factor, a numerical coefficient representing the combined effect of the structure's ductility, energy-dissipating capacity, and structural redundancy; R_c for the convective component of the accelerating liquid and R_i for the impulsive component, from Table 4.1.1b

S_1 = mapped maximum considered earthquake 5 percent damped spectral response acceleration; parameter at a period of 1 second, expressed as a fraction of the acceleration due to gravity, g, from ASCE/SEI 7-16 Fig. 22-2, 22-4, 22-5, 22-6, 22-7, and 22-8

S_{aM} = maximum considered earthquake spectral response acceleration (5 percent damped) at period T_i or T_v, taken from a site-specific acceleration response spectrum

S_c = center-to-center spacing between individual restraint cable loops, in. (mm)

S_{cM} = maximum considered earthquake spectral response acceleration (0.5 percent damped) at period T_c, taken from a site-specific acceleration response spectrum

COMMENTARY

q, q_{max} = unit shear force in circular tanks, lb/ft

Q = total membrane (tangential) shear force at the base of tank wall at a circular tank, lb (kN)

Q_{hy} = in circular tanks, hydrostatic hoop force at liquid level y ($Q_{hy} = q_{hy} \times R$), lb per foot of wall height (kN/m)

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

S_{D1} = design spectral response acceleration (5 percent damped) at a period of 1 second, as defined in 9.4.1, expressed as a fraction of the acceleration due to gravity, g

S_{DS} = design spectral response acceleration (5 percent damped) at short periods, as defined in 9.4.1, expressed as a fraction of the acceleration due to gravity, g

S_p = center-to-center spacing of elastomeric bearing pads, in. (mm)

S_s = mapped maximum considered earthquake 5 percent damped spectral response acceleration parameter at short periods, expressed as a fraction of the acceleration due to gravity g, from ASCE/SEI 7-16 Fig. 22-1, 22-3, 22-5, 22-6, 22-7, and 22-8

t_p = thickness of elastomeric bearing pads, in. (mm)

t_w = average wall thickness, in. (mm)

T_c = natural period of the first (convective) mode of sloshing, s

T_i = fundamental period of oscillation of the tank (plus the impulsive component of the contents), s

T_L = long-period transition period(s) shown in Fig. 22-14 through 22-17 of ASCE 7-16

T_S = S_{D1}/S_{DS}, s

$\ddot{u}_v$ = effective spectral acceleration from an inelastic vertical response spectrum, as defined by Eq. (4.1.4.2b), that is derived by scaling from an elastic horizontal response spectrum, expressed as a fraction of the acceleration due to gravity, g

V = total horizontal base shear, lb (kN)

w_p = width of elastomeric bearing pad, in. (mm)

W_c = effective weight of the convective component of the stored liquid, lb (kN)

COMMENTARY

S_0 = effective peak ground acceleration (at T = 0), related to the maximum considered earthquake; expressed as a fraction of the acceleration due to gravity, g, from a site-specific spectrum. (S_0 is equivalent to a PGA having a 2 percent probability of exceedance in 50 years, as given in the U.S. Geological Survey (USGS) database at website (http://earthquake.usgs.gov/hazards).

S_a = generalized design spectral response acceleration corresponding to a given natural period T, expressed as a fraction of the acceleration due to gravity, g

S_D = spectral displacement, ft (m)

T_v = natural period of vibration of vertical liquid motion, s

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials - Not for Resale, Sivaraju, Muralidhar
te.org
Not for Resale, 01/03/2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

CODE

W_e = effective dynamic weight of the tank structure (walls and roof) [$W_e = (\varepsilon W_w + W_r)$], lb (kN)
W_i = effective weight of the impulsive component of the stored liquid, lb (kN)
W_L = total weight of the stored liquid, lb (kN)
W_r = weight of the tank roof, plus superimposed load, plus applicable portion of snow load considered as dead load, lb (kN)
W_w = weight of the tank wall (shell), lb (kN)
W_w' = in a rectangular tank, the weight of one wall perpendicular to the direction of the earthquake force, lb (kN)
y = liquid level at which the wall is being investigated (measured from the base of the tank wall), ft (m)
α = angle of restraint cable or strand with horizontal, degree
β = percent of critical damping
γ_c = density of concrete, [150 lb/ft^3 (23.56 kN/m^3) for standard-weight concrete]
γ_L = density of contained liquid, lb/ft^3 (kN/m^3)
γ_w = density of water, 62.43 lb/ft^3 (9.807 kN/m^3)
ε = effective mass coefficient (ratio of equivalent dynamic mass of the tank shell to its actual total mass), Eq. (9.6a) and (9.6b)
θ = polar coordinate angle, degree
λ = coefficient as defined in 9.2.4 and 9.3.4
σ_y = membrane (hoop) stress in wall of circular tank at liquid level y, psi (MPa)
ω_c = circular frequency of oscillation of the first (convective) mode of sloshing, radian/s
ω_i = circular frequency of the impulsive mode of vibration, rad/s

1.3—Definitions

base of tank wall—the level at which the tank wall intersects the floor slab at the bottom of the tank wall and at which the horizontal earthquake ground motions are assumed to be imparted to the tank just above the floor level. This level does not necessarily coincide with the ground level.

restraint cable—epoxy-coated or galvanized steel strand, typically seven-wire, designed to resist tangential movements but permit limited radial movements of the wall.

COMMENTARY

η_c, η_i = coefficients as defined in Section R4.2
γ = density of backfill soil, lb/ft^3
γ_s = saturated unit weight of the backfill soil, lb/ft^3
γ_b = buoyant unit weight of the backfill soil, lb/ft^3

For θ, refer to Fig. R5.2.1 and R5.2.2.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

CHAPTER 2—TYPES OF LIQUID-CONTAINING STRUCTURES

2.1—Ground-supported structures

Structures in this category include rectangular and circular liquid-containing concrete structures, on-grade and below grade.

COMMENTARY

CHAPTER R2—TYPES OF LIQUID-CONTAINING STRUCTURES

R2.1—Ground-supported structures

For basic configurations of ground-supported liquid-containing structures, refer to Fig. R2.1

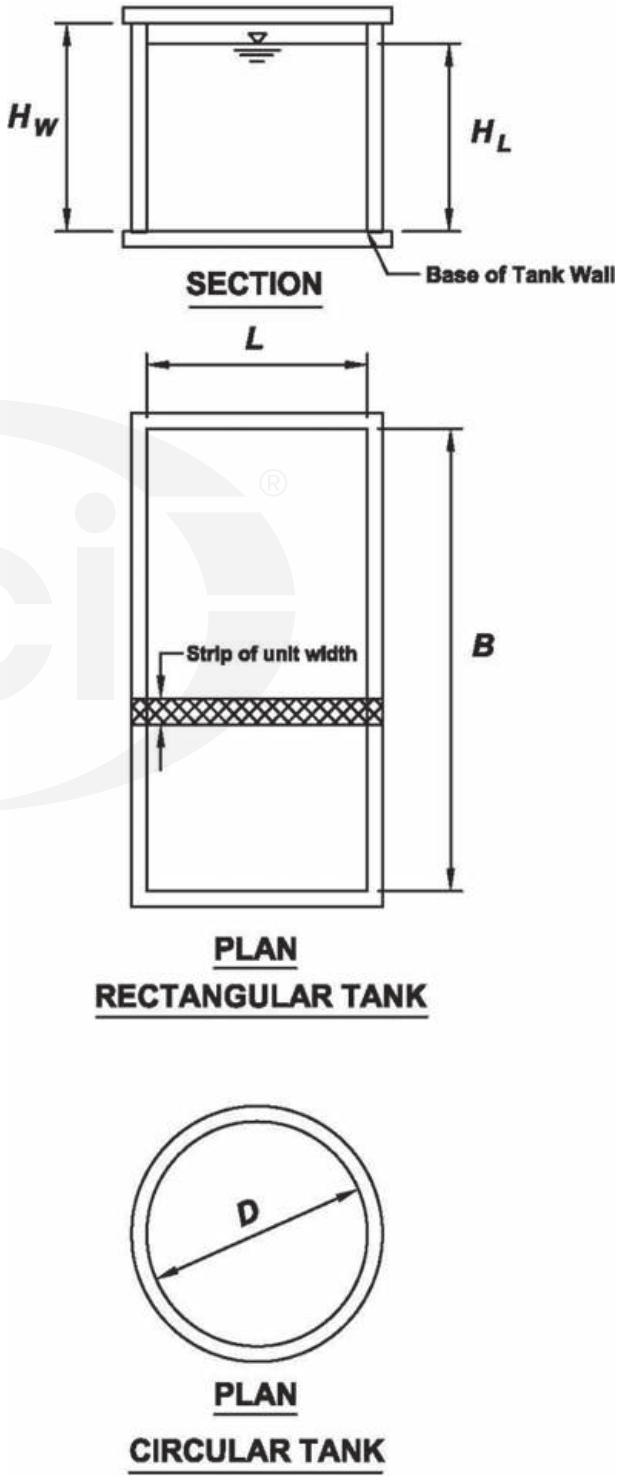

Fig. R2.1—Typical tank configurations (adapted from ASCE [1984]).

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

2.1.1 Ground-supported liquid-containing structures are classified according to this section on the basis of the following characteristics:

(a) General configuration (rectangular or circular)

(b) Wall base joint type (fixed, hinged, or flexible base)

(c) Method of construction (reinforced or prestressed concrete)

Type 1—Rectangular tanks

Type 1.1—Fixed base

Type 1.2—Hinged base

Type 2—Circular tanks

Type 2.1—Fixed base

2.1(1)—Reinforced concrete

2.1(2)—Prestressed concrete

Type 2.2—Hinged base

2.2(1)—Reinforced concrete

2.2(2)—Prestressed concrete

Type 2.3—Flexible base (prestressed only)

2.3(1)—Anchored

2.3(2)—Unanchored, contained

2.3(3)—Unanchored, uncontained

COMMENTARY

R2.1.1 The classifications of Section 2.1.1 are based on the wall-to-foundation connection details as illustrated in Fig. R2.1.1.

With any one of the tank types covered under this report the floor may be a membrane-type slab, a raft foundation, or a structural slab supported on piles.

The tank roof may be a free-span dome or column-supported flat slab; or the tank may be open-topped.

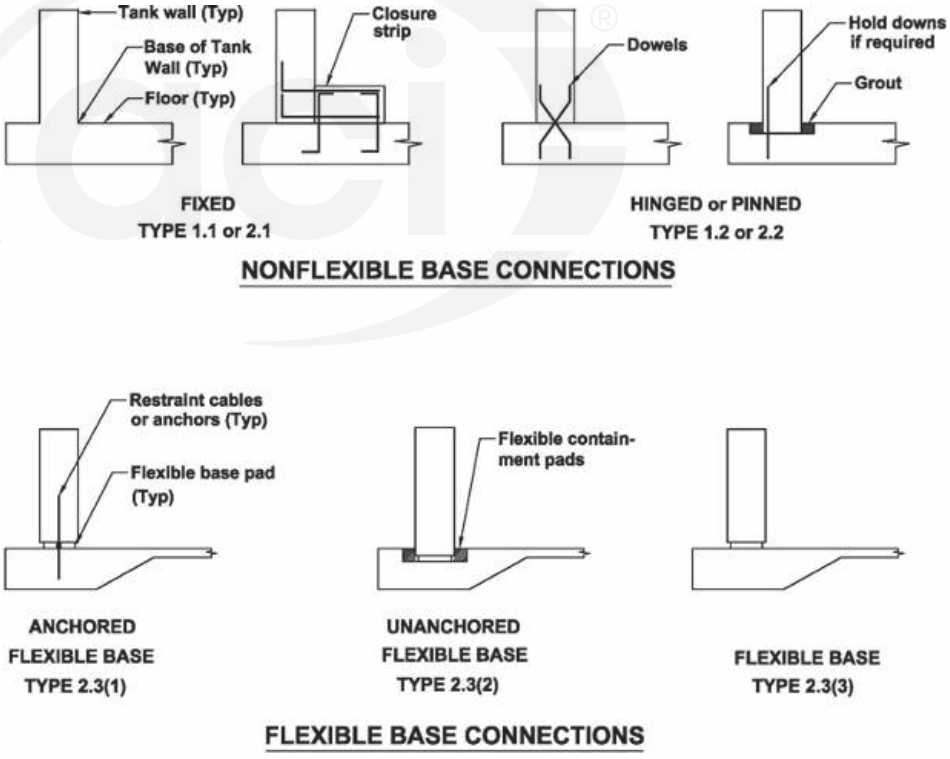

Fig. R2.1.1—Types of ground-supported liquid-containing structures classified on the basis of their wall-to-footing connection details (base waterstops not shown).

2.2—Pedestal-mounted structures

Structures in this category include liquid-containing structures mounted on cantilever-type pedestals.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

CHAPTER 3—GENERAL CRITERIA FOR ANALYSIS AND DESIGN

3.1—Dynamic characteristics

The dynamic characteristics of liquid-containing structures shall be derived in accordance with Chapter 9 or a more rigorous dynamic analysis that accounts for the interaction between the structure and the contained liquid.

3.2—Design loads

Loads generated by the design earthquake shall be computed in accordance with Chapter 4.

3.3—Design requirements

3.3.1 The walls, floors, and roofs of liquid-containing structures shall be designed to withstand the effects of both the design horizontal acceleration and the design vertical acceleration combined with the effects of the applicable design static loads.

3.3.2 With regard to the horizontal acceleration, the design shall take into account the effects of the transfer of the total shear between the wall and the foundation and between the wall and the roof, and the dynamic pressure acting on the wall above the base of the tank wall.

3.3.3 Effects of maximum horizontal and vertical acceleration shall be combined by the square-root-sum-of-the-squares method.

COMMENTARY

CHAPTER R3—GENERAL CRITERIA FOR ANALYSIS AND DESIGN

R3.1—Dynamic characteristics

For an outline of the general steps involved in the interaction between the structure and the contained liquid, refer to Appendix A.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials - Not for Commercial Use, User=Sivaraju, Muralidhar
Wed Jul 13 2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

CODE

CHAPTER 4—EARTHQUAKE DESIGN LOADS

4.1—Earthquake pressures above base of tank wall

The walls of liquid-containing structures shall be designed for the following dynamic forces in addition to the static pressures in accordance with Section 5.3:

(a) Inertia forces P_w and P_r

(b) Hydrodynamic impulsive pressure P_i from the contained liquid

(c) Hydrodynamic convective pressure P_c from the contained liquid

(d) Dynamic earth pressure from saturated and unsaturated soils against the buried portion of the wall, P_{eg}

(e) The effects of vertical acceleration

4.1.1 *Dynamic lateral forces*—The dynamic lateral forces above the base of the tank wall shall be determined as follows

$$P_w = C_i I \times \frac{\varepsilon W_w}{R_i} \quad (4.1.1a)$$

$$P_w' = C_i I \times \frac{\varepsilon W_w'}{R_i} \quad (4.1.1b)$$

$$P_r = C_i I \times \frac{W_r}{R_i} \quad (4.1.1c)$$

$$P_i = C_i I \times \frac{W_i}{R_i} \quad (4.1.1d)$$

$$P_c = C_c I \times \frac{W_c}{R_c} \quad (4.1.1e)$$

where C_i and C_c are the seismic response coefficients determined in accordance with Sections 9.4 and 9.5; I is the importance factor defined in Table 4.1.1a; W_w and W_r are the weights of the cylindrical tank wall (shell) and tank roof, respectively; and W_w' is the weight of one wall in a rectangular tank, perpendicular to the direction of the earthquake force; Notation ε is a factor defined in Section 1.2 and determined in accordance with Section 9.6; W_i and W_c are the impulsive and convective components of the stored liquid, respectively, as defined in Section 1.2, and determined in accordance with Sections 9.2.1 and 9.3.1; and R_i and R_c are the response modification factors defined in Section 1.2 and determined in accordance with Table 4.1.1b.

Where applicable, the lateral forces due to the dynamic earth pressure from saturated and unsaturated soils against the buried portion of the walls shall be computed in accordance with the provisions of Chapter 8.

COMMENTARY

CHAPTER R4—EARTHQUAKE DESIGN LOADS

R4.1—Earthquake pressures above base of tank wall

The general equation for the total base shear normally encountered in the earthquake-design sections of governing building codes, $V = C_s W$, is modified in Eq. (4.1.1a) through (4.1.1e) by replacing the term W with the four effective weights: the effective weight of the tank wall, εW_w, and roof, W_r; the impulsive component of the liquid weight W_i and the convective component W_c; and the term C_s with C_i, C_c, or C_v as appropriate.

Because the impulsive and convective components are not in phase with each other, accepted practice is to combine them using the square-root-sum-of-the-squares method (Eq. (4.1.2)) (NZS 3106; Tavakkoli et al. 2012; Veletsos and Shivakumar 1997).

A more detailed discussion of the impulsive and convective components, W_i and W_c, is contained in Section R9.1.

The imposed ground motion is represented by an elastic response spectrum that is either derived from an actual earthquake record for the site or is constructed by analogy to sites with known soil and seismic characteristics. The profile of the response spectrum is defined by S_a, which is a function of the period of vibration, and the mapped accelerations S_S and S_1, as described in Section R9.4.

Factor I provides a means for the engineer to increase the factor of safety for the categories of structures described in Table 4.1.1a. Engineering judgment may require a factor I greater than tabulated in Table 4.1.1a where it is necessary to reduce further the potential level of damage or account for the possibility of an earthquake greater than the design earthquake.

The response modification factors R_c and R_i reduce the elastic response spectrum to account for the structure's ductility, energy-dissipating properties, and redundancy (ACI 350-20 Section R13.1.1). For pedestal-mounted tanks, use the response modification factors R_i and R_c from Table 4.1.1b for all components that are in contact with the contained liquid. For components of elevated tanks that are not in contact with the contained liquid, R_i should be in accordance with ASCE/SEI 7-16.

Explanations of the impulsive and convective pressures P_i and P_c are contained in Section R9.1 and Housner (1963a).

An energy method of dynamic analysis may be used instead of the base-shear approach of Section 4.1 for sizing earthquake cables and base pad for flexible base joints (Housner 1963a; John A. Blume & Associates 1958; Medearis and Young 1964; Uang and Bertero 1988; Bertero 1995; Scarlat 1997).

With respect to seismic design, the Importance Factor (Table 4.1.1a) has the effect of reducing the ductility demand on the structure at a given level of ground shaking. Thus, it relates to how a structure responds to a design earthquake rather than as a multiplier or modifier to the design earthquake. Application of the Importance Factor, I, as a divisor on

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

Table 4.1.1a—Risk category and importance factor

Risk category	Definitions	Importance factor *I*
I	Liquid-containing structures that represent low risk to human life in the event of failure	1.00
II	All liquid-containing structures except those listed in Risk Categories I, III, and IV	1.00
III	(1) Liquid-containing structures for water treatment facilities for potable water, wastewater treatment facilities, and other public utility facilities not included in Risk Category IV (2) Liquid-containing structures, the failure of which could pose a substantial risk to human life (3) Liquid-containing structures, not included in Risk Category IV, with potential to cause a substantial economic impact, mass disruption of day-to-day civilian life, or both, in the event of failure (4) Liquid-containing structures not included in Risk Category IV, including but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction, and that is sufficient to pose a threat to the public if released	1.25
IV	(1) Liquid-containing structures designated as essential facilities (2) Water storage and pump structures required to maintain water pressure for fire suppression (3) Liquid-containing structures including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released	1.50

Notes:

1. Structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment that a release of the substance is commensurate with the risk associated with that Risk Category.

2. Toxic substances and highly toxic substances are as defined in OSHA 29 CFR 1910.1200 Appendix A with Amendments as of February 1, 2000.

Table 4.1.1b—Response modification factor *R*

Structure type	R_i		R_c
	On or above grade	Buried*	
(a) Anchored, flexible-base tanks	3.25†	3.5†	1.0
(b) Fixed or hinged-base tanks	2.25	3.25	1.0
(c) Unanchored, contained, or uncontained tanks‡	1.5	2.25	1.0
(d) Pedestal-mounted tanks§	2.25	—	1.0

*Buried tank is defined as one whose maximum water surface at rest is at or below ground level.

†For partially buried tanks, the R_i value may be linearly interpolated between that shown for tanks on grade, and for buried tanks.

‡Unanchored, uncontained tanks shall not be built in locations where $S_s \geq 0.75$.

§The R_i for the pedestal mounted tank only applies to the tank on top of the pedestal. The R value for design of the pedestal shall be as required by ASCE/SEI 7.

the Response Modification Factor, *R*, allows for a reduction of the *R* value to an effective value "*R*/*I*" as a partial control on the amount of damage experienced by the structure under a design earthquake. For a given strength demand, structures assigned Importance Factors greater than 1.0 will then effectively be designed for a reduced effective *R* factor (by means of the Importance Factor). As a result, these structures are expected to experience lower ductility demands than structures designed with lower Importance Factors and, thus, sustain less damage. Such structures should also be able to withstand larger magnitude earthquakes with less damage than structures designed with lower Importance Factors.

In addition to reduced ductility demands, good connection details, a complete load path for lateral forces, quality assurance procedures, and limitations on structure deformation or drift are also important to significantly improve the

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

4.1.2 *Total base shear*—The horizontal base shear due to seismic forces applied at the base of the tank wall shall be determined by the following equation

$$V = \sqrt{(P_i + P_w + P_r)^2 + P_c^2 + P_{eg}^2} \quad (4.1.2)$$

Where applicable, the lateral forces due to the dynamic earth pressure from saturated and unsaturated soils against the buried portion of the walls shall be included in the determination of the total horizontal base shear V.

4.1.3 *Moments at base of tank wall, general equation*—The moments due to seismic forces at the base of the tank wall shall be determined by Eq. (4.1.3e) and (4.1.3h).

Bending moment on the entire tank cross section just above the base of the tank wall (EBP)

$$M_w = P_w \times h_w \quad (4.1.3a)$$

$$M_r = P_r \times h_r \quad (4.1.3b)$$

$$M_i = P_i \times h_i \quad (4.1.3c)$$

$$M_c = P_c \times h_c \quad (4.1.3d)$$

$$M_{eg} = P_{eg} \times h_{eg} \quad (4.1.3e)$$

$$M_b = \sqrt{(M_i + M_w + M_r)^2 + M_c^2 + M_{eg}^2} \quad (4.1.3f)$$

Overturning moment at the base of the tank wall, including dynamic fluid pressure on the tank bottom (IBP)

$$M_i' = P_i' \times h_i' \quad (4.1.3g)$$

$$M_c' = P_c' \times h_c' \quad (4.1.3h)$$

$$M_o = \sqrt{(M_i' + M_w + M_r)^2 + M_c'^2 + M_{eg}^2} \quad (4.1.3i)$$

COMMENTARY

structural performance (minimizing damage) and safety of critical facilities after a seismic event.

R4.1.1 *Earthquake pressures above base of tank wall*—A model representation of W_i and W_c is shown in Fig. R9.1.

R4.1.2 *Total base shear*—Note that the total base shear calculated at the base of the tank wall in accordance with these provisions does not include inertia of the base slab. Inertia of the base slab should be included in the total base shear applied at the bottom of the tank floor slab for tank global stability evaluation.

Also note that the total base shear for rectangular tanks is calculated on a unit-width basis when using these provisions. Inertia of the tank side walls (parallel to ground motion) is not included. Inertia of these side walls should be added to the inertia of the perpendicular tank walls and be included in the total base shear for tank global stability evaluation.

R4.1.3 *Moments at base of tank wall, general equation*—IBP overturning moment M_o is the hydrodynamic overturning moment on a horizontal plane at the base of the tank wall resulting from the combined effect of the moment due to dynamic fluid pressures acting vertically on the tank bottom, and bending moment on the tank cross section.

When considering the moment due to dynamic pressures on the tank floor slab, pressures acting on the top of the tank floor slab may be computed based on M_o minus M_b. The pressure distribution can be computed as $(M_o - M_b)/(I_b/x)$, as shown in Fig. R4.1.3, where I_b is the moment of inertia of the tank bottom footprint.

When determining the soil reaction pressure or the transfer of the forces acting on supporting elements resulting from the overturning moment, the pressure distribution from dynamic fluid pressure on the tank bottom must be combined with the effects of M_b. The type of foundation and its stiffness need

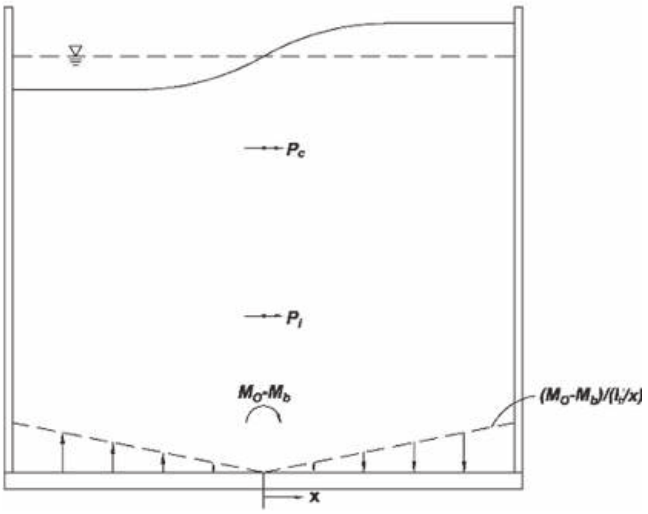

Fig. R4.1.3—Dynamic fluid pressure on the tank floor slab.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

4.1.4 *Vertical acceleration*

4.1.4.1 The tank shall be designed for the effects of vertical acceleration. In the absence of a site-specific response spectrum, the ratio b of the vertical to horizontal acceleration shall not be less than two-thirds.

4.1.4.2 The hydrostatic load q_{hy} from the tank contents, at level y above the base of the tank wall, shall be multiplied by the spectral acceleration $\ddot{u}_v$ to account for the effect of the vertical acceleration. The resulting hydrodynamic pressure p_{vy} shall be computed as follows

$$p_{vy} = \ddot{u}_v \times q_{hy} \qquad (4.1.4.2a)$$

where

$$\ddot{u}_v = C_t I \frac{b}{R_i} \geq 0.2 S_{DS} \qquad (4.1.4.2b)$$

where C_t is the seismic response coefficient determined in accordance with Sections 9.4 and 9.5.

4.2—Application of site-specific response spectra

4.2.1 *General*—Where site-specific procedures are used, the maximum considered earthquake spectral response acceleration shall be taken as the lesser of the probabilistic maximum earthquake spectral response acceleration as defined in Section 4.2.2 and the deterministic maximum spectral response acceleration as defined in Section 4.2.3.

4.2.2 *Probabilistic maximum considered earthquake*—The probabilistic maximum considered earthquake spectral response acceleration shall be taken as the spectral response acceleration represented by a 5 percent damped acceleration response spectrum having a 2 percent probability of exceedance in a 50-year period.

COMMENTARY

to be considered to determine the distribution of the reaction to M_b.

M_o should be considered for evaluating soil bearing pressure and global overturning. Consider supporting structure height or the foundation thickness when evaluating overturning and bearing pressure of the entire structure. The combined effects of bearing pressures from static forces and vertical acceleration with those resulting from seismic overturning should be considered.

R4.1.4 *Vertical acceleration*—The effective fluid pressure will be increased or decreased due to the effects of vertical acceleration. Similar changes in effective weight of the concrete structure may also be considered.

ASCE/SEI 7-16 Section 12.4.2.2 and FEMA-2 Section 4.2.2.1 use a factor of $0.2S_{DS}$ to account for the effects of vertical ground acceleration in the definition of seismic effects.

R4.2—Application of site-specific response spectra

R4.2.1 *General*—In locations with $S_S \geq 1.5$ or $S_1 \geq 0.60$, and sites with weak soil conditions, site-specific response spectra are normally used.

R4.2.2 *Probabilistic minimum considered earthquake*—For probabilistic ground motions, a 2 percent probability of exceedance in a 50-year period is equivalent to a recurrence interval of approximately 2500 years.

The damping ratio for structures is assumed as 5 percent in this Code, as is common industry practice. For sloshing liquids, the damping ratio is assumed as 0.5 percent in this Code, which is used in development of the response spectrum for the convective component of the liquid seismic force.

When the available site-specific response spectrum is for a damping ratio β other than 5 percent of critical, the period-dependent spectral acceleration S_{aM} given by such site-specific spectrum should be modified by the factor η_i to account for the influence of damping on the spectral amplification as follows (Newmark and Hall 1982):

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

4.2.3 *Deterministic maximum considered earthquake*—The deterministic maximum considered earthquake spectral response acceleration at each period shall be taken as 150 percent of the largest median 5 percent damped spectral response acceleration computed at that period for characteristic earthquakes on all known active faults within the region. The deterministic value of the spectral response acceleration shall not be taken lower than $0.6F_v/T$, except that the lower limit of the spectral response acceleration shall not exceed $1.5F_a$. The site coefficients F_a and F_v shall be obtained from ASCE/SEI 7-16 Tables 11.4-1 and 11.4-2, respectively.

4.2.4 The maximum considered earthquake spectral response accelerations S_{aM} and S_{cM} shall be determined in accordance with Section 9.5 using the site-specific acceleration response spectrum as defined in Section 4.2.1.

COMMENTARY

For $0\text{ s} < (T_i \text{ or } T_v) < T_s$

$$\eta_i = \frac{2.706}{4.38 - 1.04\ln\beta}$$

For $T_s < (T_i \text{ or } T_v) < 4.0\text{ s}$

$$\eta_i = \frac{2.302}{3.38 - 0.67\ln\beta}$$

For $\beta = 5$ percent, $\eta_i = 1.0$.

When the available site-specific response spectrum is for a damping ratio β other than 0.5 percent of critical, the period-dependent spectral acceleration S_{cM} given by that spectrum may be modified by the ratio η_c to account for the influence of damping on the spectral amplification as follows:

$$\eta_c = \frac{3.043}{2.73 - 0.45\ln\beta}$$

For $\beta = 0.5$ percent, $\eta_c = 1.0$.

For site-specific response spectra drawn on a tripartite logarithmic plot, the design spectral acceleration S_{cM} can also be derived by using the relationship

$$S_{cM} = \eta_c \frac{S_D}{g}\left(\frac{2\pi}{T_c}\right)^2 = \eta_c \frac{1.226 S_D}{T_c^2}$$

where S_D is the spectral displacement corresponding to T_c obtained directly from the site-specific spectrum in the range $T_c > 1.6/T_s$.

R4.2.3 *Deterministic maximum considered earthquake*—For deterministic ground motions, the magnitude of a characteristic earthquake on a given fault should be the best estimate of the maximum magnitude capable for that fault and should not be less than the largest magnitude that has occurred historically on the fault.

--`,,```,,,,````-`-`,,`,,`,`,,`---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyright Materials (www.concrete.org)
002, User=Sivaraju, Muralidhar
Wed Jun 8 2022 21:35:25 MST

Encuentra más documentos en www.udocz.com

CODE

CHAPTER 5—EARTHQUAKE LOAD DISTRIBUTION

5.1—General

In the absence of a more rigorous analysis that considers the complex vertical and horizontal variations in hydrodynamic pressures, liquid-containing structures shall be designed for the following dynamic shear and pressure distributions in addition to the static load distributions.

5.2—Shear transfer

5.2.1 *Rectangular tanks*—The wall-to-floor, wall-to-wall, and wall-to-roof joints of rectangular tanks shall be designed for the earthquake shear forces on the basis of the following shear-transfer mechanism:

Walls perpendicular to the direction of the earthquake force shall be analyzed as slabs subjected to the horizontal pressures computed in Section 5.3. The shears along the bottom and side joints and the top joint in case of a roof-covered tank shall correspond to the slab reactions.

Walls parallel to the direction of the earthquake force shall be analyzed as shear walls subjected to the in-plane forces computed in Section 5.3.

5.2.2 *Circular tanks*—The wall-to-foundation and wall-to-roof joints shall be designed for the earthquake shear forces.

COMMENTARY

CHAPTER 5—EARTHQUAKE LOAD DISTRIBUTION

R5.2—Shear transfer (NZS 3106)

The horizontal earthquake force V generates shear forces between the wall and foundation and the wall and roof.

R5.2.1 *Rectangular tanks*—Typically, the horizontal distribution of forces and wall reactions in rectangular tank walls will be similar to that shown in Fig. R5.2.1.

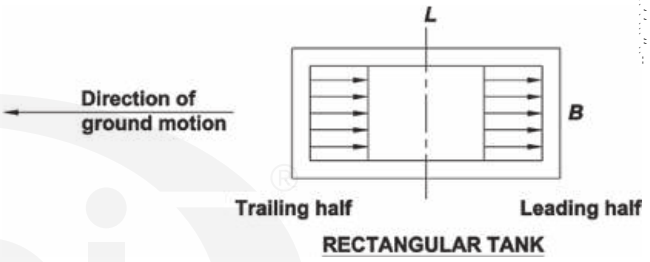

Fig. R5.2.1—Hydrodynamic pressure distribution in tank walls. (Adapted from Housner [1963a] and NZS 3106.)

R5.2.2 *Circular tanks*—Typically, the horizontal distribution of forces in circular tank walls will be similar to that shown in Fig. R5.2.2a.

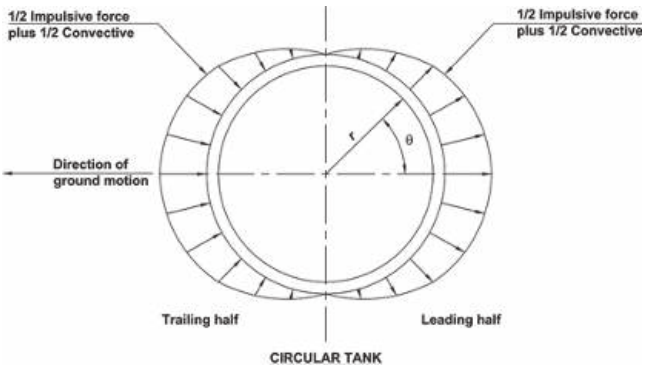

Fig. R5.2.2a—Horizontal distribution of forces in circular tank walls (adapted from NZS 3106).

In fixed- and hinged-base circular tanks (Types 2.1 and 2.2), the earthquake base shear is transmitted partially by membrane (tangential) shear and the rest by radial shear that causes vertical bending. For a tank with a height-to-diameter ratio of 1:4 ($D/H_L = 4.0$), approximately 20 percent of the earthquake shear force is transmitted by the radial base reaction to vertical bending. The remaining 80 percent is transmitted by tangential shear transfer Q. To transmit this

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

tangential shear Q, a distributed shear force q is required at the wall/footing interface, where

$$q = \frac{Q}{\pi r}\sin\theta$$

The distribution of tangential shear is illustrated in Fig. R5.2.2b.

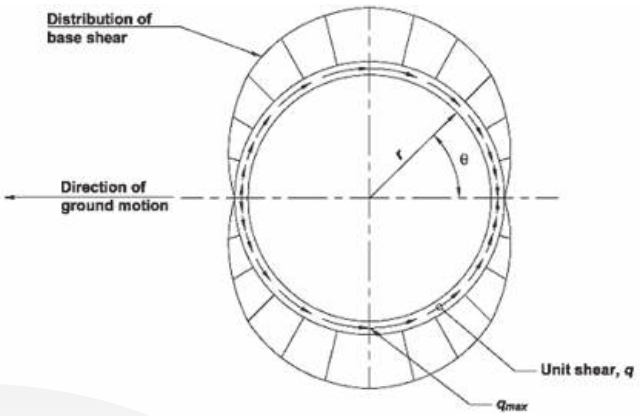

Fig. R5.2.2b—Membrane shear transfer at base of circular tank walls (adapted from NZS 3106).

The maximum tangential shear occurs at a point on the tank wall oriented 90 degrees to the design earthquake direction being evaluated and is given by

$$q_{max} = \frac{Q}{\pi r} = \frac{0.8V}{\pi r}$$

The radial shear is created by the flexural response of the wall near the base of tank wall and is therefore proportional to the hydrodynamic forces shown in Fig. R5.2.2a. The radial shear attains its maximum value at points on the tank wall oriented zero and 180 degrees to the ground motion and should be determined using cylindrical shell theory and the tank dimensions. The design of the wall-foundation interface should take the radial shear into account.

In general, the wall-footing interface should have reinforcement designed to transmit these shears through the joint. Alternatively, the wall may be located in a preformed slot in the ring beam foundation.

In anchored, flexible-base, circular tanks (Type 2.3(1)) it is assumed that the entire base shear is transmitted by membrane (tangential) shear with only insignificant vertical bending.

$$Q = 1.0V$$

$$q_{max} = \frac{Q}{\pi r} = \frac{V}{\pi r}$$

In tank Types 2.3(2) and 2.3(3), it is assumed that the base shear is transmitted by friction only. If friction between the base of the wall and the foundation, or between the base of the tank

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

wall and the bearing pads, is insufficient to resist the earthquake shear, some form of mechanical restraint such as dowels, galvanized steel cables, or preformed slots may be required.

Failure to provide a means for shear transfer around the circumference may result in sliding of the wall.

When using preformed slots, vertical bending moments induced in the wall by shear should be considered.

The roof-to-wall joint is subject to earthquake shear from the horizontal acceleration of the roof. Where dowels are provided to transfer this shear, the distribution will be the same as shown in Fig. R5.2.2b with maximum shear given by

$$q_{max} = \frac{0.8P_r}{\pi r}$$

where P_r is the force from the horizontal acceleration of the roof.

For tanks with roof overhangs, the concrete lip can be designed to withstand the earthquake force. Because the roof is free to slide on top of the wall, the shear transfer will take place over that portion of the circumference where the lip overhang comes into contact with the wall. Typically, the distribution of forces and wall reactions in circular tanks will be similar to that shown in Fig. R5.2.2a, but reacting on only half of the circumference. The maximum reaction force will be given by

$$q_{max} = \frac{2.0P_r}{\pi r}$$

5.3—Dynamic force distribution above base of tank wall

5.3.1 *Rectangular tanks*—Walls perpendicular to the earthquake force and in the leading half of the tank shall be loaded perpendicular to their plane (dimension B) by the wall's own inertia force P_w', one-half the impulsive force P_i, and one-half the convective force P_c.

Walls perpendicular to the earthquake force and in the trailing half of the tank shall be loaded perpendicular to their plane (dimension B) by the wall's own inertia force P_w', one-half the impulsive force P_i, one-half the convective force P_c, and the dynamic earth and groundwater pressure against the buried portion of the wall.

Walls parallel to the direction of the earthquake force shall be loaded in their plane (dimension L) by the wall's own in-plane inertia force P_w', and the in-plane forces corresponding to the edge reactions from the roof P_r (where applicable), and from the abutting wall(s).

Superimposed on these lateral unbalanced forces shall be the lateral hydrodynamic force resulting from the hydrodynamic pressure due to the effect of vertical acceleration, p_{vy}, acting on each wall.

R5.3—Dynamic force distribution above base of tank wall

R5.3.1 *Rectangular tanks*—The vertical distribution, per foot of wall height, of the horizontal dynamic forces acting perpendicular to the plane of the wall may be assumed as shown in Fig. 5.3.1a (adapted from NZS 3106:1986 Section 2.2.9.5) and as shown in Fig. R5.3.1b.

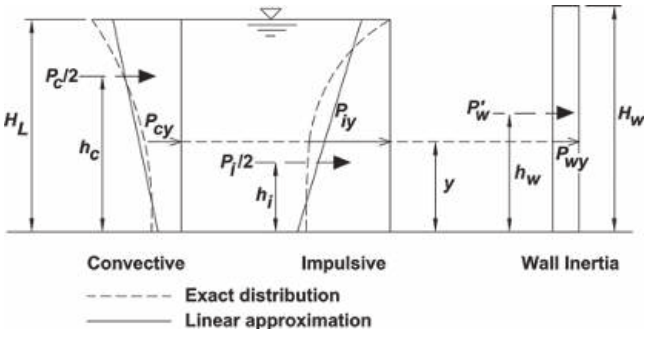

Fig. R5.3.1a—Vertical force distribution of horizontal forces: rectangular tanks.

--`,,```,,,,````-`-`,,`,,`,`,,`---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials Document (acc.org)
Not for Resale, 01/16/2022 21:33:26 MST
Sivaraju, Muralidhar

Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

$$P_{wy} = (C_i I/R_i) \times [\varepsilon(\gamma_c B t_w)]/12 \quad \text{(in.-lb)}$$

$$P_{wy} = (C_i I/R_i) \times [\varepsilon(\gamma_c B t_w)] \quad \text{(SI)}$$

Based on the exact distribution, the impulsive and convective pressure distributions are:

$$p_{iy} = \frac{P_i}{2} \times \frac{3}{2H_L}\left[1 - \left(\frac{y}{H_L}\right)^2\right]$$

$$p_{cy} = \frac{P_c}{2} \times \frac{5\sqrt{3.6}}{3L}\left[\frac{\cosh\left(\sqrt{2.5}\,\frac{2y}{L}\right)}{\sinh\left(\sqrt{2.5}\,\frac{2H_L}{L}\right)}\right]$$

Alternatively, the assumed linear distribution can be used as follows

$$P_{iy} = \frac{\frac{P_i}{2}\left[4H_L - 6h_i - \left(6H_L - 12h_i\right)\left(\frac{y}{H_L}\right)\right]}{H_L^2}$$

For $h_c < (2/3)H_L$

$$P_{cy} = \frac{\frac{P_c}{2}\left[4H_L - 6h_c - \left(6H_L - 12h_c\right)\left(\frac{y}{H_L}\right)\right]}{H_L^{\,2}} \geq 0$$

For $h_c \geq (2/3)H_L$:

For $y \leq (3h_c - 2H_L)$: $P_{cy} = 0$

For $y > (3h_c - 2H_L)$: $P_{cy} = P_c[y + 2H_L - 3h_c]/[9(H_L - h_c)^2]$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

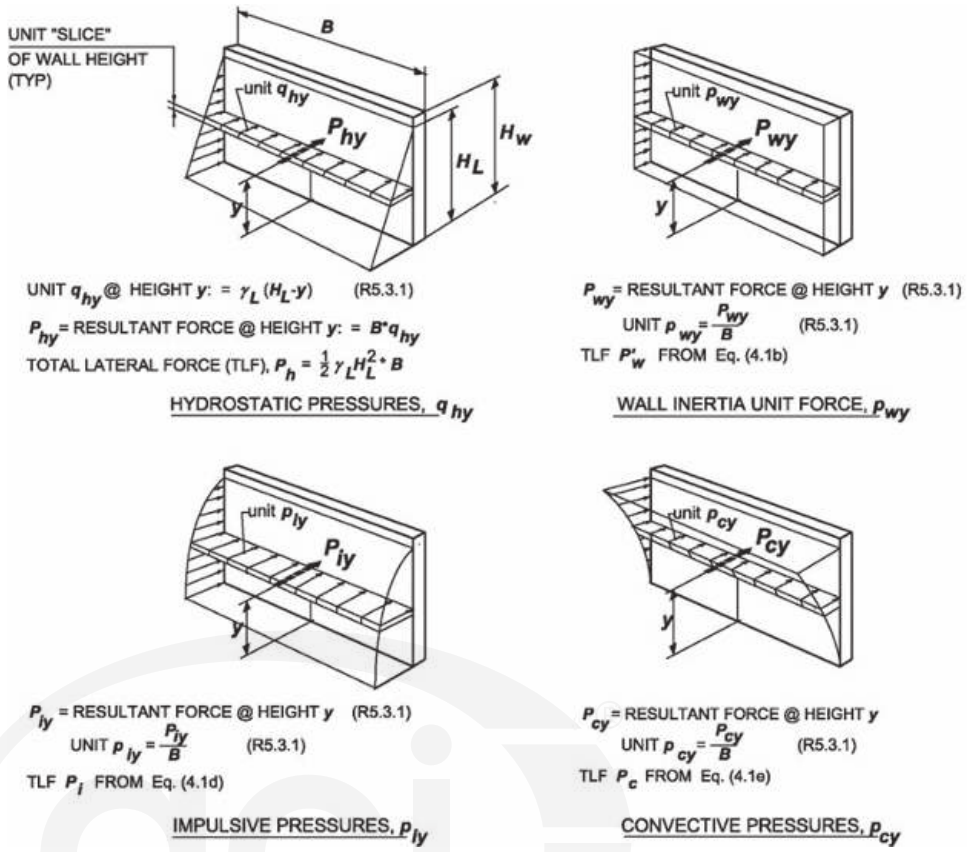

Fig. R5.3.1b—Distribution of hydrostatic and hydrodynamic pressures and inertia forces on the wall of a rectangular liquid-containing structure. (Adapted from Haroun [1984].)

The horizontal distribution of the dynamic pressures across the wall width B is

$$p_{wy} = P_{wy}/B; \quad p_{cy} = P_{cy}/B$$

$$p_{iy} = P_{iy}/B; \quad p_{vy} = \ddot{u}_v q_{hy}$$

The dynamic force on the leading half of the tank will be additive to the hydrostatic force on the wall, and the dynamic force on the trailing half of the tank will reduce the effects of the hydrostatic force on the wall.

5.3.2 *Combining dynamic forces for rectangular tanks*—The dynamic force at any given height y from the base of the tank wall shall be determined by the following equation

$$P_y = \sqrt{(P_{iy} + P_{wy})^2 + P_{cy}^2 + (p_{vy} \times B)^2} \qquad (5.3.2)$$

Where applicable, the effect of the dynamic earth pressure and from saturated and unsaturated soils against the buried portions of the walls shall be included.

R5.3.2 *Combining dynamic forces for rectangular tanks*—The shape of the dynamic soil pressure will vary depending on the soil conditions. The geotechnical professional should determine the distribution of the dynamic earth pressure at any height on the wall. Also refer to R8.1.

5.3.3 *Circular tanks*—The cylindrical walls of circular tanks shall be loaded by the wall's own inertia force distrib-

R5.3.3 *Circular tanks*—The vertical distribution, per foot of wall height, of the horizontal dynamic forces acting on

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

one half of the wall may be assumed as shown in Fig. R5.3.3 and in Fig. R5.2.2a.

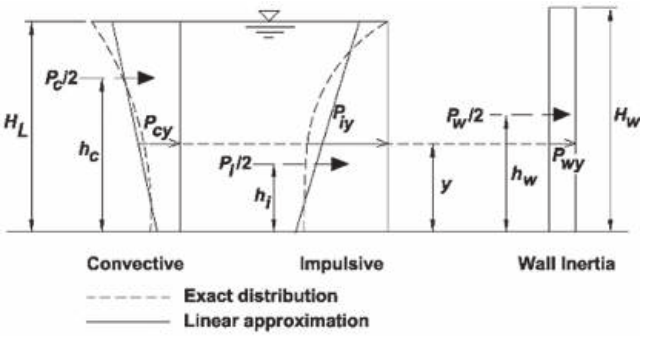

Fig. R5.3.3—Vertical force distribution:circular tanks.

$$P_{wy} = \frac{P_w}{2H_w}$$

(As shown for a constant-thickness wall. For a tapered wall, use height above floor slab to centroid of wall.)

Based on the exact distribution, the impulsive and convective pressure distributions are

$$p_{iy} = \frac{P_i}{2} \times \frac{3}{2H_L}\left[1 - \left(\frac{y}{H_L}\right)^2\right]$$

$$p_{cy} = \frac{P_c}{2} \times \frac{9}{2r\sqrt{6}}\left[\frac{\cosh\left(\sqrt{3.375}\,\frac{y}{r}\right)}{\sinh\left(\sqrt{3.375}\,\frac{H_L}{r}\right)}\right]$$

Alternatively, the assumed linear distribution can be used as follows

$$P_{iy} = \frac{\frac{P_i}{2}\left[4H_L - 6h_i - (6H_L - 12h_i)\left(\frac{y}{H_L}\right)\right]}{H_L^2}$$

For $h_c < (2/3)H_L$:

$$P_{cy} = \frac{\frac{P_c}{2}\left[4H_L - 6h_c - (6H_L - 12h_c)\left(\frac{y}{H_L}\right)\right]}{H_L^2} \geq 0$$

For $h_c \geq (2/3)H_L$:

For $y \leq (3h_c - 2H_L)$: $P_{cy} = 0$
For $y > (3h_c - 2H_L)$: $P_{cy} = P_c[y + 2H_L - 3h_c]/[9(H_L - h_c)^2]$

(For circular tanks, the vertical distribution of the impulsive and convective forces is identical to that shown in Fig. R5.3.1b for rectangular tanks, while the horizontal distribution varies along the tank circumference as shown in Fig. R.5.2.2a.)

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

uted uniformly around the entire circumference; one-half the impulsive force P_i applied symmetrically about $\theta = 0$ and acting outward on one half of the wall, and one-half P_i symmetrically about $\theta = \pi$ and acting inward on the opposite half of the wall; one-half the convective force P_c, acting on one-half of the wall symmetrically about $\theta = 0$ and one-half P_c symmetrically about $\theta = \pi$ and acting inward on the opposite half of the wall; and the dynamic earth pressure and from saturated and unsaturated soil against the trailing half of the buried portion of the wall. Superimposed on these lateral unbalanced forces shall be the axisymmetric lateral hydrodynamic force resulting from the hydrodynamic pressure p_{vy} acting on the tank wall.

Roof inertia generates hoop forces with sinusoidal variation in the circumferential direction in the dome ring/top of the wall region. In case of flat roof, the extent of top of the wall resisting roof inertia depends on wall-roof connection details. In case of dome roof, this region is defined by the dome ring. Below this region, the roof inertia generates shear stresses which can be computed by treating the entire cross section of the tank as hollow circular section (or hollow rectangular section). The roof inertia should be added to the impulsive component of liquid when computing total base shear.

COMMENTARY

The horizontal distribution of the dynamic pressure across the tank diameter D may be assumed as follows

$$p_{wy} = P_{wy}/\pi r; \qquad p_{cy} = (16P_{cy}/9\pi r) \times \cos\theta$$

$$p_{iy} = (2P_{iy}/\pi r) \times \cos\theta; \qquad p_{vy} = \ddot{u}_v q_{hy}$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

CHAPTER 6—STRESSES

6.1—Rectangular tanks

The vertical and horizontal bending stresses and shear stresses in the wall and at the base of the tank wall due to lateral earthquake forces shall be computed on the basis of slab action (Sections 5.2 and 5.3), using pressure distribution consistent with the provisions of Section 5.3.1.

6.2—Circular tanks

The vertical bending stresses and shear stresses in the wall and at the base of the tank wall due to lateral earthquake forces shall be computed on the basis of shell action using an acceptable pressure distribution.

Dynamic membrane (hoop) forces in the cylindrical wall corresponding to any liquid level, y, above the base of the tank wall shall be determined by the following equation

$$N_y = \sqrt{(N_{iy} + N_{wy})^2 + N_{cy}^{\ 2} + N_{hy}^{\ 2}} \qquad (6.2a)$$

and hoop stress

$$\sigma_y = \frac{N_y}{12t_w} \quad \text{(in.-lb)} \qquad \sigma_y = \frac{N_y}{t_w} \quad \text{(SI)} \qquad (6.2b)$$

where t_w is wall thickness at the level being investigated (liquid level y). Where applicable, the effects of the dynamic earth pressure and from saturated and unsaturated soils against the buried portions of the walls shall be included.

COMMENTARY

CHAPTER R6—STRESSES

R6—General

In calculating the vertical bending moments in the walls of rectangular and circular tanks, the boundary conditions at the wall-to-base and wall-to-roof joints should be properly accounted for. Typical earthquake force distributions in walls of rectangular and circular tanks are presented in R5.3.1 and R5.3.3, respectively.

R6.2—Circular tanks

For free-base circular tanks (Type 2.3), the terms in Eq. (6.2a) are defined as follows

$$N_{iy} = p_{iy} \times r = \frac{2P_{iy}}{\pi} \text{ for (at } \theta = 0)$$

$$N_{cy} = p_{cy} \times r = \frac{16P_{cy}}{\pi} \text{ for (at } \theta = 0)$$

$$N_{wy} = p_{wy} \times r = \frac{P_{wy}}{\pi}$$

$$N_{hy} = \ddot{u}_v \times Q_{hy}$$

where

$$Q_{hy} = q_{hy} \times r$$

For fixed- or hinged-base circular tanks (Types 2.1 and 2.2) the terms in Eq. (6.2a) should be modified to account for the effects of base restraint. Similarly, the terms in Eq. (6.2a) should be modified to account for the restraint of rigid wall-to-roof joints. Out-of-phase dynamic forces (inertia, impulsive, convective and vertical acceleration) generally have widely spaced frequencies of vibration from individual modes and there is minimal coupling between modes. The effects of the out-of-phase forces may be combined using a method such as the square-root-sum-of-the-squares (SRSS) method.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

CHAPTER 7—FREEBOARD

7.1—Wave oscillation

Provisions shall be made to accommodate the maximum wave oscillation d_{max} generated by earthquake acceleration.

The maximum vertical displacement d_{max} to be accommodated shall be calculated from the following expressions:

Rectangular tanks

$$d_{max} = \frac{L}{2} C_c I \tag{7.1a}$$

In lieu of the simplified Eq. (7.1a), d_{max} may be calculated using Eq. (7.1b)

$$d_{max} = \frac{0.264L}{\left(\frac{2g}{\omega_c^2 C_c L} - 1\right) \tanh\left(\frac{3.16H_L}{L}\right)} I \tag{7.1b}$$

Circular tanks

$$d_{max} = \frac{D}{2} C_c I \tag{7.1c}$$

In lieu of the simplified Eq. (7.1c), d_{max} can be calculated using Eq. (7.1d)

$$d_{max} = \frac{0.204D}{\left(\frac{2g}{\omega_c^2 C_c D} - 1\right) \tanh\left(\frac{3.68H_L}{D}\right)} I \tag{7.1d}$$

where C_c is the seismic response coefficient as computed in Section 9.4.

COMMENTARY

CHAPTER R7—FREEBOARD

R7.1—Wave oscillation

The horizontal earthquake acceleration causes the contained fluid to slosh with vertical displacement of the fluid surface.

The amount of freeboard required in design to accommodate this sloshing will vary. Where overtopping is tolerable no freeboard provision is necessary. Where loss of liquid should be prevented (for example, tanks for the storage of toxic liquids), or where overtopping may result in scouring of the foundation materials or cause damage to pipes, roof, or both, then one or more of the following measures should be undertaken:

(a) Provide a freeboard allowance

(b) Design the roof structure to resist the resulting uplift pressures, and design the tank to include the confined portion of the convective (sloshing) mass as an additional impulsive mass; and/or

(c) Provide an overflow spillway

Two sets of equations are provided to calculate the vertical displacement of the fluid surface. Equations (7.1a) and (7.1c) are a simplified and conservative approach consistent with ASCE/SEI 7-16. Equations (7.1b) and (7.1d) are taken from TID-7024 (Housner 1963a), including the corrected Appendix F, which addresses an integration error in the published θ_h equation for cylindrical containers. The variable θ_h, defined in TID-7024, is equivalent to C_c as defined in this Code. The simplified equations conservatively result in values 10 to 20 percent greater than the exact results. The sloshing height and required freeboard differences between this code and ASCE 7 are currently under consideration by ACI 350.

Observations of rectangular tanks during seismic events and modeling of tanks on shake tables as well as finite element investigations (Tavakkoli et al. 2012) have indicated a potential significant increase in slosh height at tank corners. Instead of detailed analysis, the corner sloshing can be estimated by combining sloshing height in each orthogonal direction by use of the square-root-sum-of-the-squares (SRSS) method. More accurate estimation of the corner sloshing may be determined by further detailed analysis.

When a covered tank has inadequate freeboard, the sloshing wave will impact the roof and cause an upward pressure on the roof structure. Other codes, both in the United States (ASCE/SEI 7) and in other countries (EN 1998-4(2006) [Eurocode 8]; NZS 3106; AIJ [2010]) do not have a consistent method for calculating the upward force. Research papers (Malhotra 2005; Goudarzi et al. 2010; Douglass et al. 2006; Isaacson 2010; Kobayashi 1980), whether based on scale-model experiments or based on purely analytical approaches, give widely varying answers to the problem. Because of the widely varying results of the research, a more complex method will not necessarily give a more accurate pressure. The following simplified method may be used to calculate the uplift force.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

This method is based on "Wave Forces on Bridge Decks" by Douglass et al. (2006).

Loads on flat roofs covering rectangular or circular tanks: The upward force on a flat roof structure has two components: a buoyant component and an impact component. The authors state, "The two types of loads, 'impact' and slowly 'varying' [buoyant] will be additive but not necessarily in phase, i.e. they won't both be at their peak at the same moment in time." The buoyant component is the force from 1.0 times the liquid density times the wave height above the bottom of the flat roof. The impact force can be taken as some multiple of the buoyant force. Various papers give values for the impact force ranging from 0.0 (ACI 350-20) to 3.0 (IBC 2003) times the buoyant force. The buoyant and impulsive forces should be combined using SRSS. This is consistent with how the impulsive and convective forces are combined in this Code. The selection of the value of the impact force is left to the licensed design professional. It is recommended that the value of C_{LF} in the following equation be taken as no less than 1.4 (impact force equal to 1.0 times buoyant force), and a reasonable upward bound for C_{LF} may be 3.2 (impact force equal to 3.0 times the buoyant force). A reasonable compromise value for C_{LF} is 2.2.

The upward fluid pressure on the underside of the flat roof structure may be determined by

$$F_R/A_v = C_{LF}\gamma_L(d_{max}/I - h_o)$$

where C_{LF} is the coefficient that is the SRSS combination of the buoyant and impulsive multipliers; F_R is the total upward force on the flat roof structure from an impacting wave, lb; A_v is the area the flat roof impacted by the wave, ft^2; and h_o is the distance from undisturbed water surface to underside of roof (freeboard).

The flat roof structure within a distance of L_i of the wall will be subject to an upward pressure of F_R/A_v, where L_i may be determined by:

Length of flat roof impacted by wave in circular tanks

$$L_i = D/2 - D/\pi\sin^{-1}(h_o/d_{max})$$

Length of flat roof impacted by wave in rectangular tanks

$$L_i = (L/\pi)\cos^{-1}(h_o/d_{max})$$

Upward fluid pressure and length of roof impacted by wave will be smaller in the case of dome roofs. It will be necessary to modify the aforementioned equations to account for the curvature of dome roofs. Alternately, the flat roof calculations may be conservatively used.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

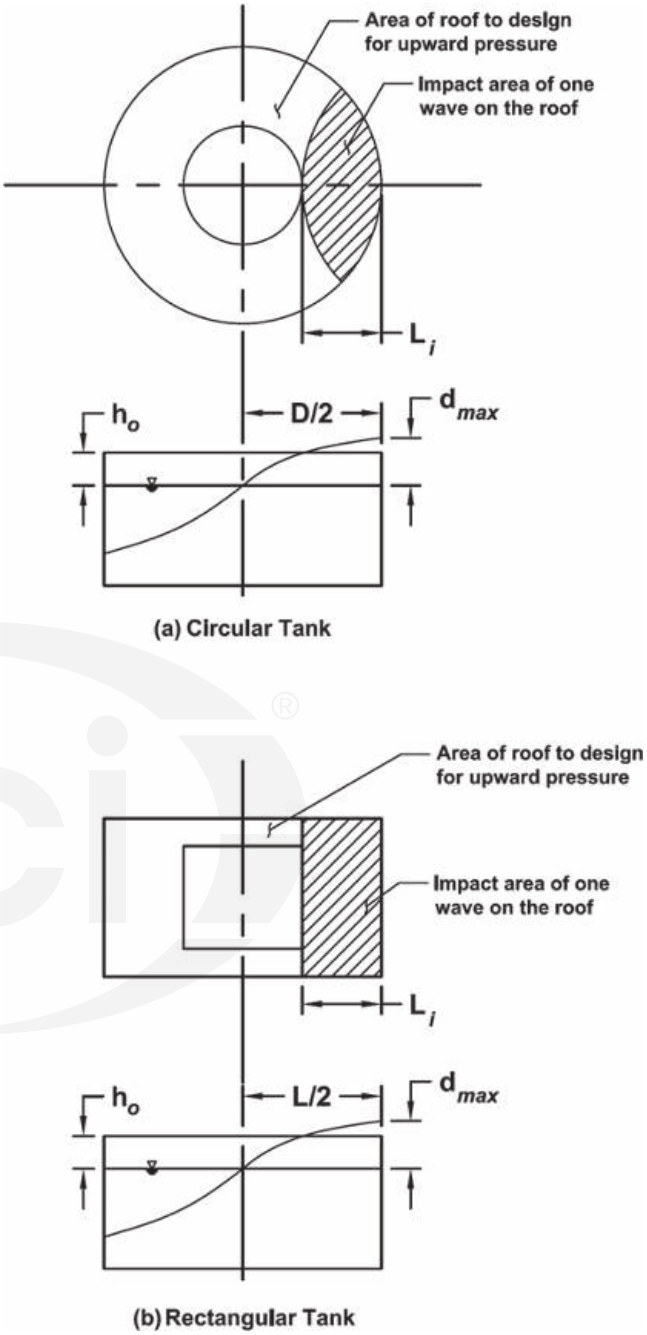

Fig. R7.1—Wave impact area on the roofs of tanks.

Wall loads for tanks with inadequate freeboard

When the wave impacts the roof, in addition to loading the roof, there will be an increase in the impulsive mass of water and a reduction in the convective mass as a result of the roof constraining an otherwise free fluid surface. ASCE/SEI 7-16 requires that "the design of the tank shall use the confined portion of the convective (sloshing) mass as an additional impulsive mass." The following method accomplishes this.

The wall forces may be determined using the method given in Bandyopadhyay et al. (1993).

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

In the following equations, $k_c \times 100$ is the percentage of the total roof area that is impacted by the wave; similarly for k_r.

Wall forces in circular tanks with inadequate freeboard

At minimum, the total base shear and moment should not be less than the corresponding values computed assuming that the adequate freeboard is provided.

Excluding bottom pressure

$$P_{i\text{-}w} = [(1 - k_c)W_i + k_c(H_w/H_L)W_L]C_i(I/R_i)$$

$$P_{c\text{-}w} = (1 - k_c)C_c(I/R_c)W_c$$

$$M_{i\text{-}w} = [(1 - k_c)W_i h_i + k_c(H_w/H_L)W_L(H_w/2)]C_i(I/R_i)$$

$$M_{c\text{-}w} = P_{c\text{-}w}h_c$$

where $P_{i\text{-}w}$ and $P_{c\text{-}w}$ are the impulsive and convective forces on the wall of a tank with inadequate freeboard, respectively, and $M_{i\text{-}w}$ and $M_{c\text{-}w}$ are, respectively, the impulsive and convective moments at the base of the wall of a tank with inadequate freeboard

$$k_c = [2q_o + \sin(2q_o)]/2p$$

$$q_o = \cos^{-1}(h_o/d_{max})$$

where q_o is in radians.

The resultant wall pressure may be assumed to be trapezoidal with the resultant force and height calculated as:

Resultant wall force = $\sqrt{P_{i\text{-}w}{}^2 + P_{c\text{-}w}{}^2}$

Height to resultant wall force =

$$\sqrt{M_{i\text{-}w}{}^2 + M_{c\text{-}w}{}^2}/\sqrt{P_{i\text{-}w}{}^2 + P_{c\text{-}w}{}^2}$$

Including bottom pressure

$$M_{i\text{-}w}' = [(1 - k_c)W_i h_i' + k_c(H_w/H_L)W_L(H_w/2)]C_i(I/R_i)$$

$$M_{c\text{-}w}' = (1 - k_c)P_c h_c'$$

where $M_{i\text{-}w}'$ and $M_{c\text{-}w}'$ are the impulsive and convective overturning moments of a tank with inadequate freeboard.

Wall forces in rectangular tanks with inadequate freeboard

At minimum, the total base shear and moment should not be less than the corresponding values computed assuming that the adequate freeboard is provided.

Excluding bottom pressure

$$P_{i\text{-}w} = [(1 - k_r)W_i + k_r(H_w/H_L)W_L]C_i(I/R_i)$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

$$P_{c\text{-}w} = (1 - k_r)C_c(I/R_c)W_c$$

$$M_{i\text{-}w} = [(1 - k_r)W_i h_i + k_r(H_w/H_L)W_L(H_w/2)]C_i(I/R_i)$$

$$M_{c\text{-}w} = (1 - k_r)P_c h_c$$

where

$$k_r = \theta_o/\pi$$

$$\theta_o = \cos^{-1}(h_o/d_{max})$$

where θ_o is in radians.

The resultant wall pressure may be assumed to be trapezoidal with the resultant force and height calculated as:

Resultant wall force = $\sqrt{P_{i\text{-}w}^{\ 2} + P_{c\text{-}w}^{\ 2}}$

Height to resultant wall force =

$$\sqrt{M_{i\text{-}w}^{\ 2} + M_{c\text{-}w}^{\ 2}}/\sqrt{P_{i\text{-}w}^{\ 2} + P_{c\text{-}w}^{\ 2}}$$

Including bottom pressure

$$M_{i\text{-}w}' = [(1 - k_r)W_i h_i' + k_r(H_w/H_L)W_L(H_w/2)]C_i(I/R_i)$$

$$M_{c\text{-}w}' = (1 - k_r)P_c h_c'$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)

American Concrete Institute Copyrighted Materials (ACI Members) - Not for Resale, 01/13/2022 21:34:25 MST

Encuentra más documentos en www.udocz.com

CODE

CHAPTER 8–EARTHQUAKE-INDUCED EARTH PRESSURES

8.1—General

Dynamic earth pressures shall be taken into account when computing the base shear of a partially or fully buried liquid-containing structure, and when designing the walls.

The effects of groundwater table, if present, shall be included in the calculation of these pressures. K_o, the coefficient of lateral earth pressure at rest, shall be used in estimating the earth pressures, unless it is demonstrated by calculation that the structure deflects sufficiently to lower the coefficient to some value between K_o and K_a, the active coefficient of lateral earth pressure.

In a pseudo-static analysis, the resultant of the seismic component of the earth pressure shall be assumed to act at a point 0.6 of the earth height above the base of the tank wall, and when part or all of the structure is below the water table, the resultant of the incremental increase in water pressure shall be assumed to act at a point one-third of the water depth above the base of the tank wall.

COMMENTARY

CHAPTER R8—EARTHQUAKE-INDUCED EARTH PRESSURES

R8.1—General

The lateral forces due to dynamic earth pressures are combined with other earthquake-induced pressures on the tanks using the square-root-sum-of-the-squares method (SRSS) as in Eq. (4.1.2).

Earthquake-induced earth pressures should be provided in the site geotechnical report. However, when not otherwise available, the earthquake-induced earth pressures may be calculated using the following for walls with level backfill.

Earthquake-induced earth pressure in the absence of groundwater

In the absence of a geotechnical report that provides the earthquake-induced earth pressures, the following may be used in locations without groundwater:

For walls that can move sufficiently to develop active earth pressures (yielding walls), the earthquake-induced earth pressure P_{eg} may be determined by

$$P_{eg} = (3/8)(S_{DS}/2.5)\gamma H^2(I/R) \quad \text{(R8.1a)}$$

For walls that cannot move sufficiently to develop active earth pressures (non-yielding walls), the earthquake-induced earth pressure P_{eg} may be determined by

$$P_{eg} = (S_{DS}/2.5)\gamma H^2(I/R) \quad \text{(R8.1b)}$$

The resultant force should be applied at $0.6H$ above the base of the tank wall.

Equations (R8.1a) and (R8.1b) are taken from FEMA 450-2. These are the simplified Monobe-Okabe (M-O) formulations for the increased lateral pressures on retaining structures during earthquakes.

Earthquake-induced earth pressure where groundwater is present

The earthquake-induced earth pressure P_{eg} may be determined by:

Yielding walls

$$P_{eg} = (3/8)k_{hw}(S_{DS}/2.5)\gamma H^2(I/R) \quad \text{(R8.1c)}$$

Non-yielding walls

$$P_{eg} = k_{hw}(S_{DS}/2.5)\gamma H^2(I/R) \quad \text{(R8.1d)}$$

$$k_{hw} = \gamma_s/\gamma_b \quad \text{(R8.1e)}$$

where γ_s is saturated unit weight of the backfill, and γ_b is buoyant unit weight of the backfill = $\gamma_s - \gamma_w$.

The resultant force should be applied at $0.6H$ above the base of the tank wall.

The equations for earthquake-induced earth pressure where groundwater is present are taken from ASCE/SEI 7-16.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

The equations given here assume that groundwater is at grade.

The aforementioned equations do not apply at soils that are subjected to liquefaction, as determined by a professional geotechnical engineer. Soil liquefaction is a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, such as earthquake shaking, causing it to behave like a liquid.

8.2—Limitations

In a buried tank, the dynamic backfill forces shall not be relied upon to reduce the dynamic effects of the stored liquid or vice versa.

8.3—Alternative methods

The provisions of this chapter shall be permitted to be superseded by recommendations of the project geotechnical engineer that are approved by the building official having jurisdiction.

R8.3—Alternative methods

ASCE/SEI 7-16 requires a geotechnical investigation report for structures assigned to Seismic Design Categories C, D, E, and F. However, earthquake-induced earth pressures are only required for geotechnical reports for structures assigned to Seismic Design Categories D, E, and F.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)

Encuentra más documentos en www.udocz.com

CODE

CHAPTER 9—DYNAMIC MODEL

9.1—General

The dynamic characteristics of ground-supported liquid-containing structures subjected to earthquake acceleration shall be computed in accordance with Sections 9.2, 9.3, and 9.5.

The dynamic characteristics of pedestal-mounted liquid-containing structures shall be computed in accordance with Section 9.7.

COMMENTARY

CHAPTER R9—DYNAMIC MODEL

R9.1—General

The following commentary is adapted from Housner (1963a):

The design procedures described in Chapter 4 recognize that the seismic analysis of liquid-containing structures subjected to a horizontal acceleration should include the inertia forces generated by the acceleration of the structure itself, and the hydrodynamic forces generated by the horizontal acceleration of the contained liquid.

According to Housner (1963a), the pressures associated with these forces "…can be separated into impulsive and convective parts. The impulsive pressures are not impulses in the usual sense but are associated with inertia forces produced by accelerations of the walls of the container and are directly proportional to these accelerations. The convective pressures are those produced by the oscillations of the fluid and are therefore the consequences of the impulsive pressures."

Figure R9.1 shows an equivalent dynamic model for calculating the resultant seismic forces acting on a ground-based fluid container with rigid walls. This model has been accepted by the profession since the early 1960s. In this model W_i represents the resultant effect of the impulsive seismic pressures on the tank walls. W_c represents the resultant effect of the sloshing (convective) fluid pressures.

In the model, W_i is rigidly fastened to the tank walls at a height h_i above the base of tank wall, that corresponds to the location of the resultant impulsive force P_i. W_i moves with the tank walls as they respond to the ground shaking (the fluid is assumed to be incompressible and the fluid displacements small). The impulsive pressures are generated by the seismic accelerations of the tank walls so that the force, P_i, is evenly divided into a pressure force on the wall accelerating into the fluid, and a suction force on the wall accelerating away from the fluid. During an earthquake, the force P_i changes direction several times per second, corresponding to the change in direction of the base acceleration; the overturning moment generated by P_i is thus frequently ineffective in tending to overturn the tank. Impulsive forces, however, are conservatively included in the overturning forces due to the difficulty in establishing the true effect on overturning.

W_c is the effective weight of the oscillating fluid that produces the convective pressures on the tank walls with resultant force P_c, which acts at a height of h_c above the base of the tank wall. In the model, W_c is fastened to the tank walls by springs that produce a period of vibration corresponding to the period of fluid sloshing. The sloshing pressures on the tank walls result from the fluid motion associated with the wave oscillation. The period of oscillation of the sloshing depends upon the ratio of fluid depth to tank diameter and is usually several seconds. The overturning moment exerted by P_c (Fig. R9.1) acts for a sufficient time to tend to uplift the tank wall if there is insufficient restraining weight. The forces P_i and P_c act independently and simultaneously on the

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

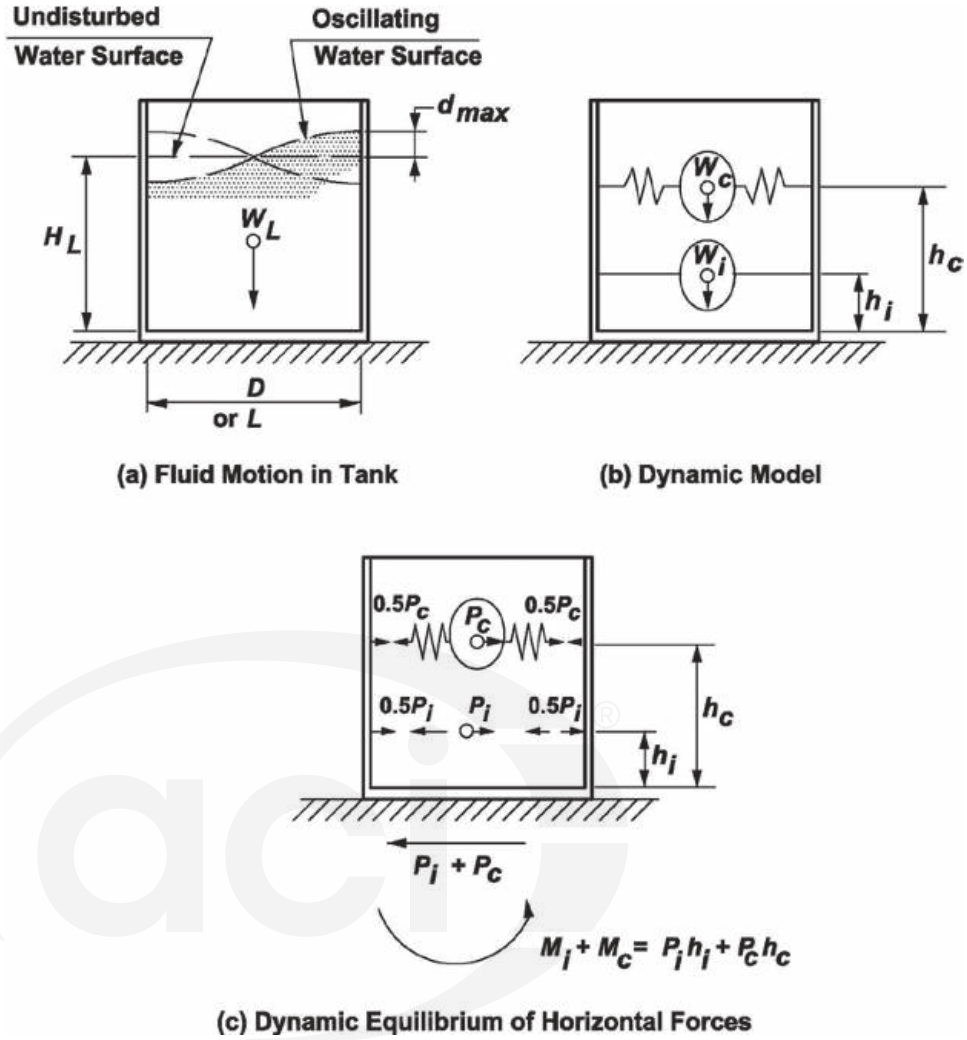

Fig. R9.1—Dynamic model of liquid-containing tank rigidly supported on the ground.

tank. The force P_i (and its associated pressures) primarily acts to stress the tank wall, whereas P_c acts primarily to uplift the tank wall. The vertical vibrations of the ground are also transmitted to the fluid and, thus, producing pressures that acts on the tank walls. They act to increase or decrease the hoop stresses.

The pressures and forces on a cylindrical tank are similar to but not the same as those acting on a rectangular tank.

The rapid fluctuations of the force P_i mean that the bending moments and stresses in the wall of a rectangular tank also vary rapidly (the effect is not like a constant force acting on the wall). The duration of the fluctuations is 10 to 15 seconds for earthquakes of magnitude 6.5 to 7.5.

The force P_c fluctuates sinusoidally with a period of vibration that depends on the dimensions of the tank and can be several seconds or longer. The duration of sloshing can be 20 to 40 seconds for earthquakes of magnitude 6.5 to 7.5. Note that the damping of the sloshing water is small, approximately 0.5 to 1 percent of critical damping. The sloshing increases and decreases the fluid pressure on the

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

COMMENTARY

wall. Normally, this is smaller than the impulsive effect, but if there is not enough dead load, the tank will tend to uplift.

9.2—Rectangular tanks (Type 1)

R9.2—Rectangular tanks (Type 1)

All equations in Section 9.2 except Eq. (9.2.4a), (9.2.4b), and (9.2.4c) were originally developed by Housner (1963a) and subsequently used by other authors (Housner 1956; NZS 3106; Haroun 1984; ASCE 1981; Veletsos and Shivakumar 1997; ANSI/AWWA D110-13 (R18); ANSI/AWWA D115-17; FEMA 450-2; ASCE/SEI 7-16; Haroun and Ellaithy 1985).

Equations (9.2.4a), (9.2.4b), and (9.2.4c) were adapted from NZS 3106.

9.2.1 *Effective weights of accelerating liquid (Fig. 9.2.1)*

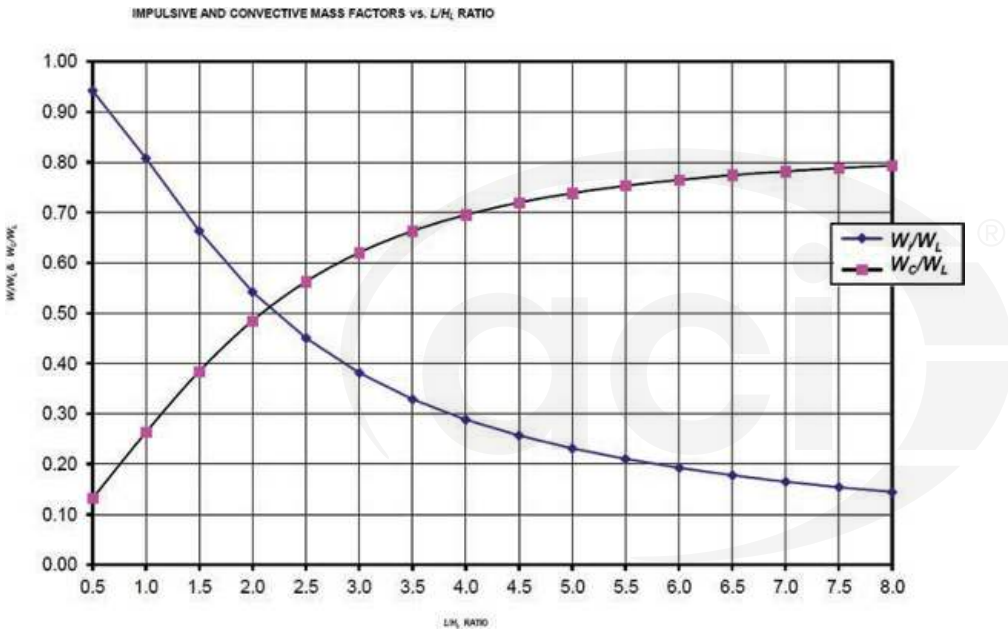

Fig. 9.2.1—Factors W_i/W_L *and* W_c/W_L *versus ratio* L/H_L *for rectangular tanks.*

$$W_i/W_L = \frac{\tanh\left[0.866(L/H_L)\right]}{0.866(L/H_L)} \qquad (9.2.1a)$$

$$W_c/W_L = 0.264(L/H_L)\tanh[3.16(H_L/L)] \qquad (9.2.1b)$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

9.2.2 *Height to centers of gravity EBP (Fig. 9.2.2)*

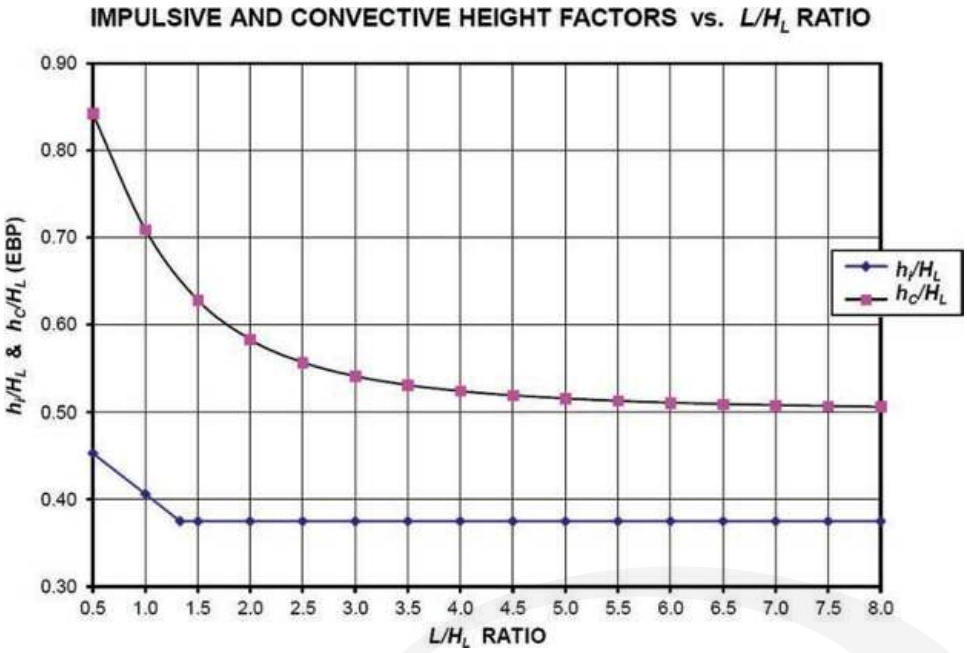

Fig. 9.2.2—Factors h_i/H_L *and* h_c/H_L *versus ratio* L/H_L *for rectangular tanks (EBP).*

For tanks with $L/H_L < 1.333$

$$h_i/H_L = 0.5 - 0.09375(L/H_L) \qquad (9.2.2a)$$

For tanks with $L/H_L \geq 1.333$

$$h_i/H_L = 0.375 \qquad (9.2.2b)$$

For all tanks

$$h_c/H_L = 1 - \frac{\cosh\left[3.16(H_L/L)\right] - 1}{3.16(H_L/L)\sinh\left[3.16(H_L/L)\right]} \qquad (9.2.2c)$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

9.2.3 *Heights to center of gravity (IBP) (Fig. 9.2.3)*

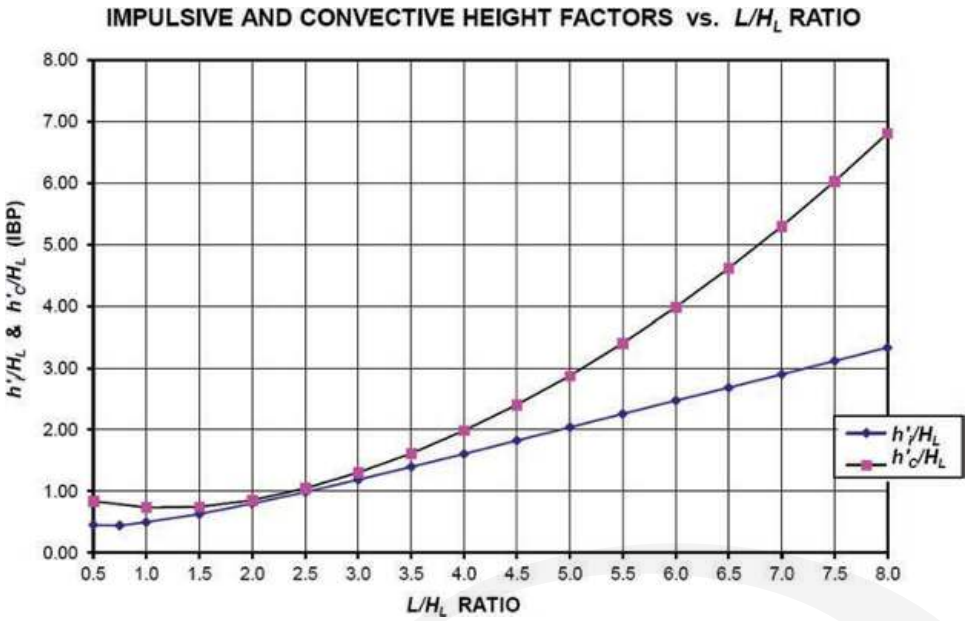

Fig. 9.2.3—Factors h_i'/H_L *and* h_c'/H_L *versus ratio* L/H_L *for rectangular tanks (IBP).*

For tanks with $L/H_L < 0.75$

$$h_i'/H_L = 0.45 \qquad (9.2.3a)$$

For tanks with $L/H_L \geq 0.75$

$$h_i'/H_L = \frac{0.866(L/H_L)}{2\tanh[0.866(L/H_L)]} - 0.125 \qquad (9.2.3b)$$

For all tanks

$$h_c'/H_L = 1 - \frac{\cosh\left[3.16(H_L/L)\right] - 2.01}{3.16(H_L/L)\sinh\left[3.16(H_L/L)\right]} \qquad (9.2.3c)$$

9.2.4 *Dynamic properties*—The structural stiffness k shall be computed on the basis of correct boundary conditions.

$$\omega_i = \sqrt{\frac{k}{m}} \qquad (9.2.4a)$$

$$m = m_w + m_i \qquad (9.2.4b)$$

$$T_i = \frac{2\pi}{\omega_i} = 2\pi\sqrt{\frac{m}{k}} \qquad (9.2.4c)$$

$$\omega_c = \frac{\lambda}{\sqrt{L}} \qquad (9.2.4d)$$

where

$$\lambda = \sqrt{3.16g\tanh\left[3.16(H_L/L)\right]} \qquad (9.2.4e)$$

R9.2.4 *Dynamic properties*—The following equations are provided as examples for the special case of a wall of uniform thickness. (Note that mass is equal to weight divided by the acceleration due to gravity.)

$$m_w = H_w t_w\left(\frac{\gamma_c}{12g}\right) \quad \text{(in.-lb)}$$

$$m_w = H_w t_w\left(\frac{\gamma_c}{g}\right) \quad \text{(SI)}$$

$$m_i = \left(\frac{W_i}{W_L}\right)\left(\frac{L}{2}\right)H_L\left(\frac{\gamma_L}{g}\right) \quad \text{(in.-lb)}$$

$$m_i = \left(\frac{W_i}{W_L}\right)\left(\frac{L}{2}\right)H_L\left(\frac{\gamma_L}{g}\right)\times 10^3 \quad \text{(SI)}$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

$$T_c = \frac{2\pi}{\omega_c} = \left(\frac{2\pi}{\lambda}\right)\sqrt{L} \qquad (9.2.4f)$$

$\left(\frac{2\pi}{\lambda}\right)$ is from Fig. 9.2.4.

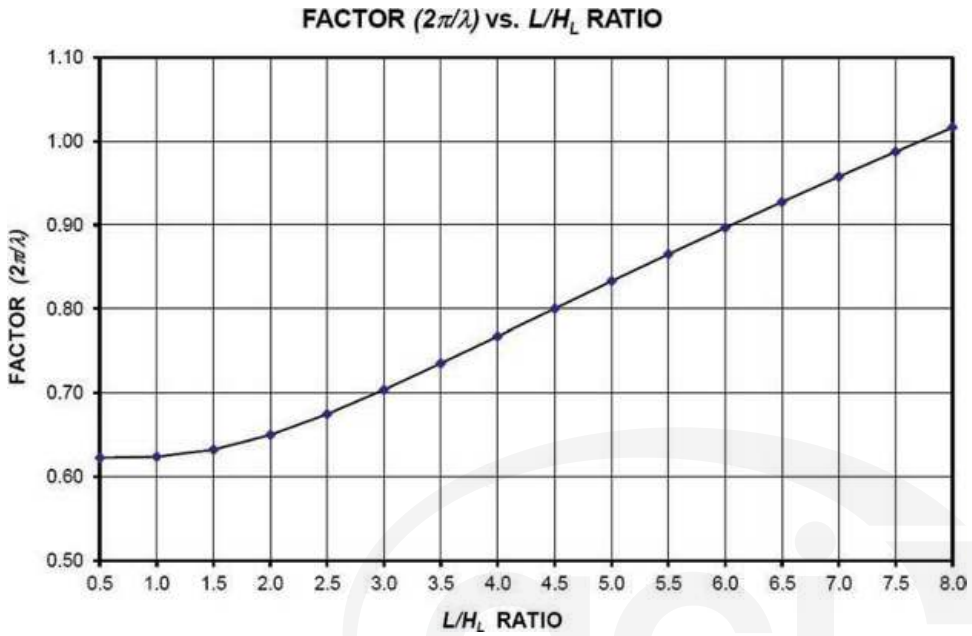

Fig. 9.2.4—Factor 2π/λ for rectangular tanks.

(For results in the SI system, multiply the factors on the vertical axis by 1.811.)

COMMENTARY

$$h = \frac{(h_w m_w + h_i m_i)}{(m_w + m_i)}$$

where $h_w = 0.5H_w$, and h_i is obtained from Eq. (9.2.2a) and (9.2.2b), and F_i.

For walls of nonuniform thickness, special analysis is required to determine m_w, m_i, and h.

For fixed-base, free-top cantilever walls such as in open-top tanks, flexural stiffness for a unit width of wall may be approximated using the following equation

$$k = \frac{E_c}{48}\left(\frac{t_w}{h}\right)^3 \quad \text{(in.-lb)}$$

$$k = \frac{E_c}{4\times10^3}\left(\frac{t_w}{h}\right)^3 \quad \text{(SI)}$$

Flexural stiffness formulas may be developed for other wall support conditions. Such spring constants will generally fall within the low period range (less than approximately 0.3 seconds) for tanks of normal proportions.

As an alternative to computing the natural period of vibration, particularly for end conditions other than cantilever, it is reasonable to assume the wall rigid. In such cases, Eq. (9.4.1b) may be conservatively used to calculate the impulsive forces regardless of the actual boundary conditions of the structure or structural components being analyzed.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

9.3—Circular tanks (Type 2)

9.3.1 *Effective weights of accelerating liquid (Fig. 9.3.1)*

$$W_i/W_L = \frac{\tanh\left[0.866(D/H_L)\right]}{0.866(D/H_L)} \quad (9.3.1a)$$

$$W_c/W_L = 0.230(D/H_L)\tanh[3.68(H_L/D)] \quad (9.3.1b)$$

COMMENTARY

R9.3—Circular tanks (Type 2)

All equations in Section 9.3 except Eq. (9.3.4a) through (9.3.4f) were originally developed by Housner (1963a) and subsequently used by other authors (Housner 1956; NZS 3106; Haroun 1984; ASCE 1981; Veletsos and Shivakumar 1997; ANSI/AWWA D110-13 (R18); ANSI/AWWA D115-17; Haroun and Ellaithy 1985).

Equations (9.3.4a) through (9.3.4f) were adapted from NZS 3106.

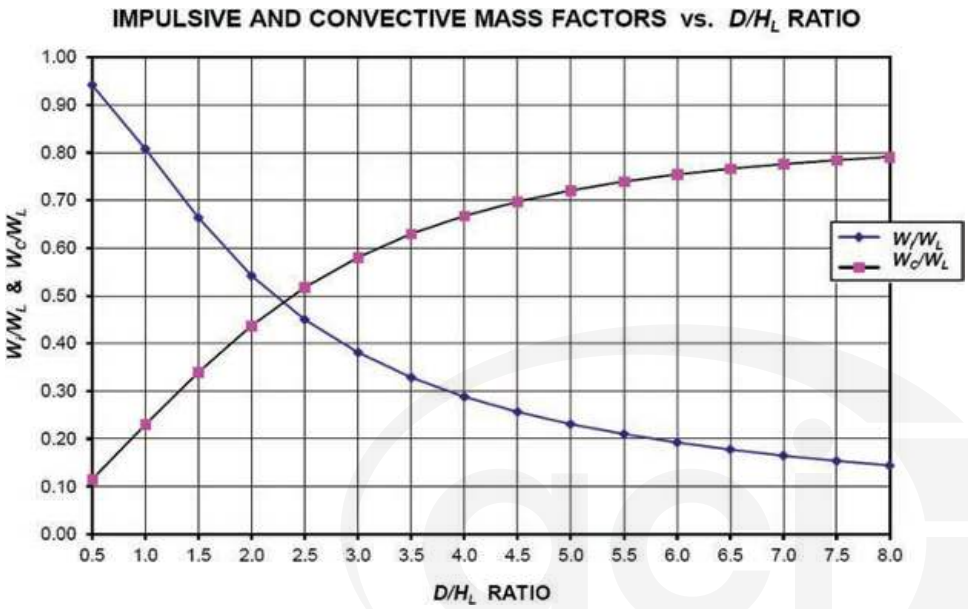

Fig. 9.3.1—Factors W_i/W_L *and* W_c/W_L *versus ratio* D/H_L *for circular tanks.*

9.3.2 *Heights to centers of gravity (EBP) (Fig. 9.3.2)*

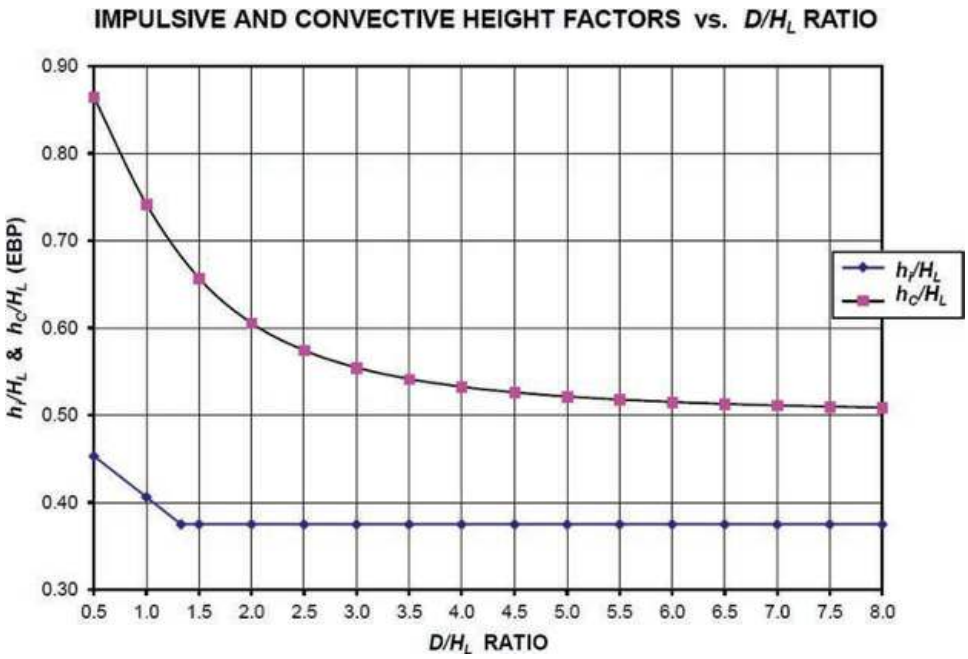

Fig. 9.3.2—Factors h_i/H_L *and* h_c/H_L *versus ratio* D/H_L *for circular tanks (EBP).*

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

For tanks with $D/H_L < 1.333$

$$h_i/H_L = 0.5 - 0.09375(D/H_L) \quad (9.3.2a)$$

For tanks with $D/H_L \geq 1.333$

$$H_i/H_L = 0.375 \quad (9.3.2b)$$

For all tanks

$$h_c/H_L = 1 - \frac{\cosh\left[3.68(H_L/D)\right] - 1}{3.68(H_L/D)\sinh\left[3.68(H_L/D)\right]} \quad (9.3.2c)$$

9.3.3 *Heights to center of gravity (IBP) (Fig. 9.3.3)*

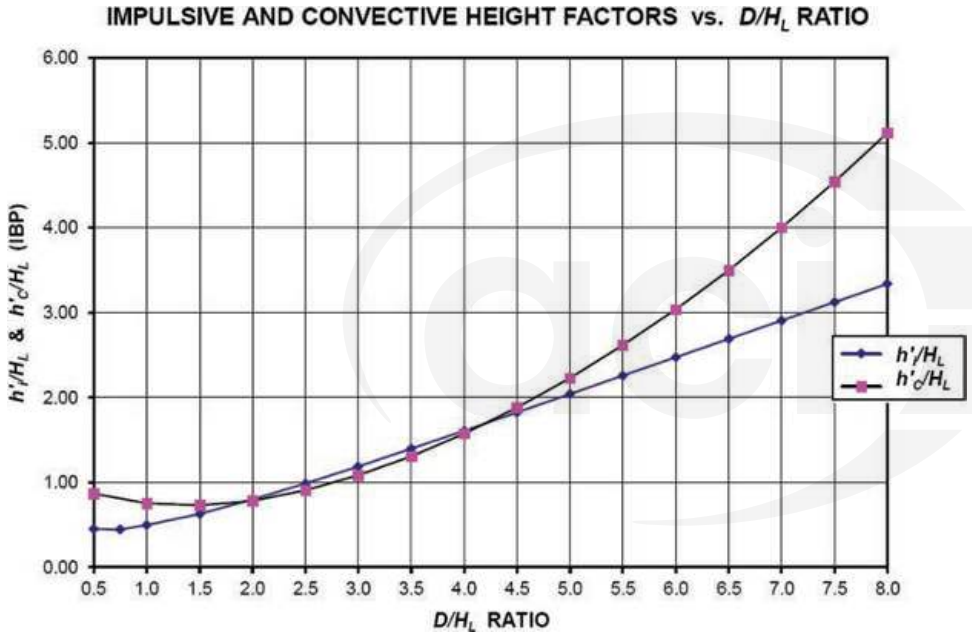

Fig. 9.3.3—Factors h_i'/H_L *and* h_c'/H_L *versus ratio* D/H_L *for circular tanks (IBP).*

For tanks with $D/H_L < 0.75$

$$h_i'/H_L = 0.45 \quad (9.3.3a)$$

For tanks with $D/H_L \geq 0.75$

$$h_i'/H_L = \frac{0.866(D/H_L)}{2\tanh\left[0.866(D/H_L)\right]} - 0.125 \quad (9.3.3b)$$

$$h_c'/H_L = 1 - \frac{\cosh\left[3.68(H_L/D)\right] - 2.01}{3.68(H_L/D)\sinh\left[3.68(H_L/D)\right]} \quad (9.3.3c)$$

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

9.3.4 *Dynamic properties*
For tank Types 2.1 and 2.2:

$$\omega_i = C_l \times \frac{12}{H_L}\sqrt{\frac{E_c g}{\gamma_c}} \quad \text{(in.-lb)} \qquad (9.3.4a)$$

$$\omega_i = C_l \times \frac{1}{H_L}\sqrt{\frac{10^3 \times E_c g}{\gamma_c}} \quad \text{(SI)}$$

$$C_l = C_w \times 10\sqrt{\frac{t_w}{12r}} \quad \text{(in.-lb)} \qquad (9.3.4b)$$

$$C_l = C_w \times \sqrt{\frac{t_w}{10r}} \quad \text{(SI)}$$

C_w from Fig. 9.3.4a

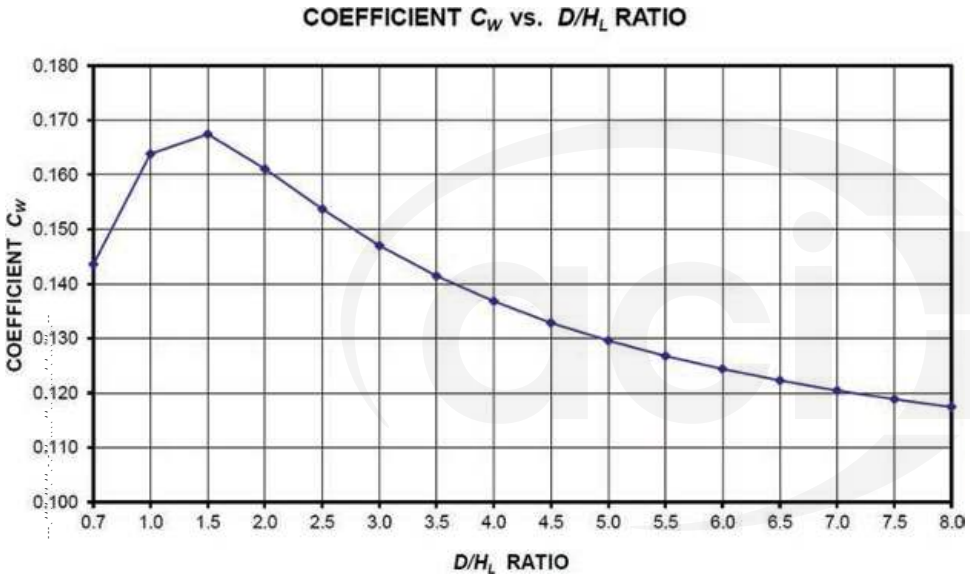

Fig. 9.3.4a—Coefficient C_w *for circular tanks.*

For $D/H_L > 0.667$

$$C_w = 9.375 \times 10^{-2} + 0.2039(H_L/D) - 1.034(H_L/D)^2 - 0.1253(H_L/D)^3 + 0.1267(H_L/D)^4 - 3.186 \times 10^{-2}(H_L/D)^5$$

$$T_i = 2\pi/\omega_i \qquad (9.3.4c)$$

For tank Type 2.3

$$T_i = \sqrt{\frac{8\pi(W_w + W_r + W_i)}{gDk_a}} \qquad (9.3.4d)$$

but shall not exceed $1.25s$

COMMENTARY

R9.3.4 *Dynamic properties*—Equations (9.3.4a) and (9.3.4b) are adapted from ASCE (1981) and Veletsos and Shivakumar (1997).

Equations (9.3.4d) and (9.3.4e) are adapted from ANSI/AWWA D110-13 (R 18) and ANSI/AWWA D115-17.

Equations (9.2.4e), (9.2.4f), (9.3.4g), and (9.3.4h) are adapted from Housner (1963a).

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE COMMENTARY

$$k_a = 144\left[\left(\frac{A_s E_s \cos^2\alpha}{L_c S_c}\right)+\left(\frac{2G_p w_p L_p}{t_p S_p}\right)\right] \quad \text{(in-lb)}$$

$$k_a = 10^6\left[\left(\frac{A_s E_s \cos^2\alpha}{L_c S_c}\right)+\left(\frac{2G_p w_p L_p}{t_p S_p}\right)\right] \quad \text{(SI)} \qquad (9.3.4e)$$

T_c

$$\omega_c = \frac{\lambda}{\sqrt{D}} \qquad (9.3.4f)$$

where

$$\lambda = \sqrt{3.68g\tanh\left[3.68(H_L/D)\right]} \qquad (9.3.4g)$$

$$T_c = \frac{2\pi}{\omega_c} = \left(\frac{2\pi}{\lambda}\right)\sqrt{D} \qquad (9.3.4h)$$

$\left(\frac{2\pi}{\lambda}\right)$ from Fig. 9.3.4b

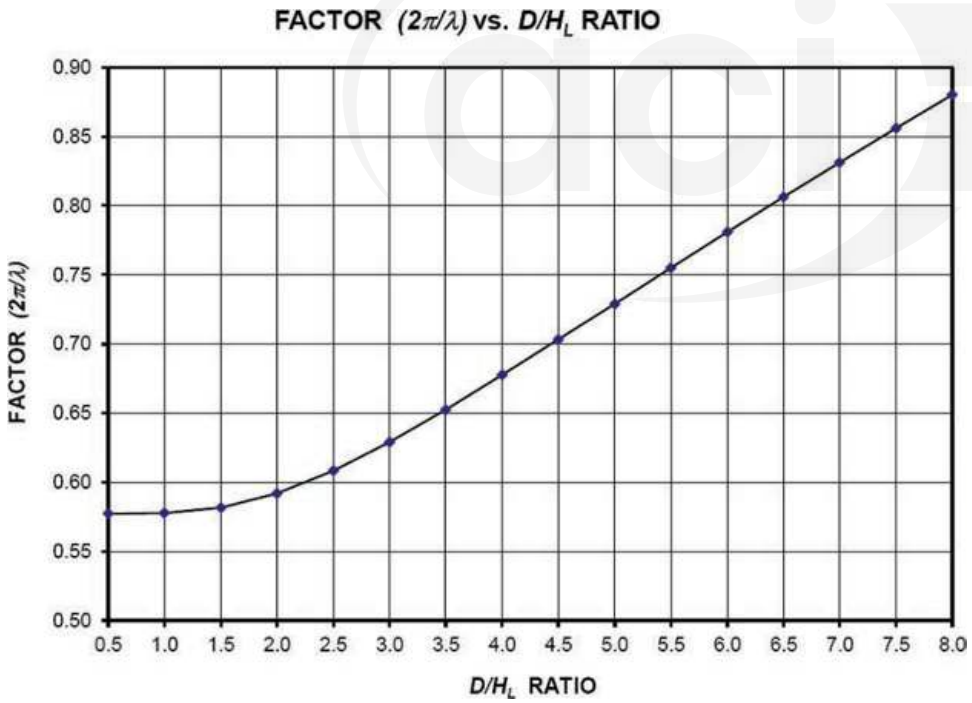

Fig. 9.3.4b—Factor 2π/λ for circular tanks.

(For results in the SI system, multiply the factors on the vertical axis by 1.811.)

--``,,```,,`,,`,,,,,,``,,,,,,,,`-`-`,,`,,`,`,,`---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials Not for Commercial Use, User=Sivaraju, Muralidhar
Wed Jul 06 2022 21:34:25 MST
Encuentra más documentos en www.udocz.com

CODE

9.4—Seismic response coefficients C_i, C_c, and C_t

9.4.1 C_i shall be determined as follows:
For $T_i \le T_S$

$$C_i = S_{DS} \tag{9.4.1a}$$

For $T_i > T_S$

$$C_i = \frac{S_{D1}}{T_i} \le S_{DS} \tag{9.4.1b}$$

where

$$T_S = \frac{S_{D1}}{S_{DS}} \tag{9.4.1c}$$

S_{DS} is the design spectral response acceleration at short periods.

$$S_{DS} = \frac{2}{3} S_S F_a \tag{9.4.1d}$$

S_{D1} is the design spectral response acceleration at 1 *s* period.

$$S_{D1} = \frac{2}{3} S_1 F_v \tag{9.4.1e}$$

S_S and S_1 are the mapped spectral response accelerations at short periods (S_s) and 1-second (S_1) respectively, and shall be obtained from the seismic ground motion maps 22-1 through 22-7 of ASCE/SEI 7-16 Section 22; and F_a and F_v are the site coefficients and shall be obtained from Tables 11.4-1 and 11.4-2, respectively, of ASCE/SEI 7-16, in conjunction with Table 20.3-1, "Site Classification," of ASCE/SEI 7-16.

COMMENTARY

R9.4—Seismic response coefficients C_i, C_c, and C_t

Designations C_i, C_c, and C_t define the profile of the design response spectrum at periods T_i, T_c, and T_v respectively. A plot of the seismic response coefficient C_i is shown in the design response spectrum in Fig. R9.4.1, which is adapted from IBC-2003.

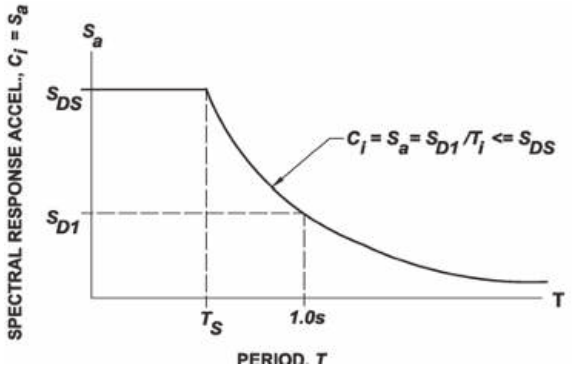

Fig. R9.4.1—Design response spectrum (5 percent damping).

R9.4.1 The mapped spectral response accelerations S_S and S_1 for any location can also be obtained from the latest database of the United States Geological Survey (USGS), at its website http://earthquake.usgs.gov/hazards/ using the specific zip code or latitude and longitude that identify the location.

In regions other than those shown in the maps in IBC-2012, FEMA 450-2, or ANSI/AWWA D115-17, S_S and S_1 may be replaced by the maximum considered earthquake spectral response accelerations from 5 percent damped response spectra representing earthquakes with a 2 percent probability of exceedance in a 50-year period, equivalent to a recurrence interval of approximately 2500 years.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

9.4.2 C_c shall be determined as follows:
For $T_c \le T_L$

$$C_c = \frac{1.5S_{D1}}{T_c} \le 1.5S_{DS} \quad (9.4.2a)$$

For $T_c > T_L$

$$C_c = \frac{1.5S_{D1}T_L}{T_c^2} \quad (9.4.2b)$$

9.4.3 C_t shall be determined as follows:
For circular tanks

$$C_t = S_{DS} \quad (9.4.3a)$$

For rectangular tanks

$$C_t = C_i \quad (9.4.3b)$$

9.5—Site-specific seismic response coefficients C_i, C_c, and C_t

When site-specific procedures are used, the maximum considered earthquake spectral response accelerations S_{aM} and S_{cM} shall be obtained from the site-specific acceleration spectrum as follows:

S_{aM} shall be the spectral response acceleration corresponding to T_i. When a 5 percent damped, site-specific vertical response spectrum is available, S_{aM} shall be determined from that spectrum as required for periods less than T_S.

For periods less than or equal to T_S, S_{aM} shall be taken as the spectral acceleration obtained from the site-specific spectrum at a period of 0.2 seconds, except that it shall not be taken less than 90 percent of the peak spectral acceleration at any period larger than 0.2 seconds. For periods greater than T_S, S_{aM} shall be taken as the spectral response acceleration corresponding to T_i. When a 5 percent damped, site-specific vertical response spectrum is available, S_{aM} in Eq. (9.6.1) shall be determined from that spectrum as required for periods less than T_S.

For vertical acceleration of circular tanks, for all periods S_{aM} shall be as required for periods less than T_S. For rectangular tanks, C_t shall be determined in accordance with Section 9.4.3.

COMMENTARY

R9.4.2 Factor 1.5 represents the approximate ratio of the spectral amplifications based on 0.5 percent damping to those based on 5 percent damping. $0.4S_{DS}$ in Eq. (9.4.3b) is an approximation of the effective peak ground acceleration, S_0 (at $T = 0$) reduced by a factor of two-thirds.

R9.4.3 Axisymmetric pulsating ("breathing") of the cylindrical wall of a circular tank (upright cylinder) occurs due to the hydrodynamic pressures resulting from the vertical, piston-like "pounding" of the stored liquid by the vertically accelerating ground. For practical tank sizes, the period of vibration of vertical liquid motion will be less than T_S and the peak spectral response acceleration may be used for design.

For reference, the natural period of vibration of vertical liquid motion in a circular tank may be calculated as

$$T_v = 2\pi\sqrt{\frac{\gamma_L D H_L^2}{24 g t_w E_c}} \quad \text{(in.-lb)}$$

$$T_v = 2\pi\sqrt{\frac{\gamma_L D H_L^2}{2 g t_w E_c}} \quad \text{(SI)}$$

For rectangular tanks, vertical accelerations of the fluid will result in pulsating horizontal pressures on the walls, resulting in a similar dynamic response for both horizontal and vertical ground motions.

R9.5—Site-specific seismic response coefficients C_i, C_c, and C_t

For damping ratios other than 5 percent of critical, refer to R4.2.

If the site-specific response spectrum does not extend into, or is not well defined in, the T_c range, coefficient C_c may be calculated using the equation

$$C_c = 6\frac{\frac{2}{3}S_0}{T_c^2} = \frac{4S_0}{T_c^2}$$

where S_0 is the effective site-specific peak ground acceleration (at $T = 0$) expressed as a fraction of the acceleration due to gravity, g.

The use of site-specific response spectra represents one specific case of an accepted alternative method of analysis as permitted in Section 13.1.1.9 of ACI 350-20. Therefore, the 80 percent lower limit imposed in 9.5 should be considered the same as the limit imposed in Section 13.1.1.9 of ACI 350-20.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CODE

S_{cM} shall be taken as 150 percent of the spectral response acceleration corresponding to T_c, except that when a 0.5 percent damped, site-specific horizontal response spectrum is available, S_{cM} shall be equal to the spectral response acceleration from that spectrum corresponding to period T_c.

The seismic response coefficients C_i, C_c, and C_t shall be determined from Eq. (9.5a), (9.5b), and (9.5c), respectively, for all periods.

$$C_i = \frac{2}{3} S_{aM} \quad (9.5a)$$

$$C_c = \frac{2}{3} S_{cM} \quad (9.5b)$$

$$C_t = \frac{2}{3} S_{aM} \quad (9.5c)$$

The values of C_i, C_c, and C_t used for design shall not be less than 80 percent of the corresponding values as determined in accordance with Section 9.4.

COMMENTARY

9.6—Effective mass coefficient ε

9.6.1 *Rectangular tanks*—For nonflexible base tanks

$$\varepsilon = [0.0151(L/H_L)^2 - 0.1908(L/H_L) + 1.021] \leq 1.0 \quad (9.6.1)$$

For flexible base tanks, ε = 1.0.

9.6.2 *Circular tanks*—For nonflexible base tanks

$$\varepsilon = [0.0151(D/H_L)^2 - 0.1908(D/H_L) + 1.021] \leq 1.0 \quad (9.6.2)$$

For flexible base tanks, ε = 1.

R9.6—Effective mass coefficient ε

The coefficient ε represents the ratio of the equivalent (or generalized) dynamic mass of the tank shell to its actual total mass. Equations (9.6a) and (9.6b) are adapted from Tavakkoli et al. (2012).

For additional information related to the effective mass coefficient ε, consult ASCE (1981).

9.7—Pedestal-mounted tanks

The effective weights W_i and W_c, and heights to the centers of gravity h_i, h_c, h_i', and h_c' of a mounted tank, shall be computed using the corresponding equations in Sections 9.2 and 9.3 for rectangular and circular tanks, respectively.

The dynamic properties, including periods of vibration and lateral coefficients, shall be permitted to be determined on the basis of generally acceptable methods of dynamic analysis.

R9.7—Pedestal-mounted tanks

Housner (1963a), ASCE/SEI 7-16, ASCE (1984), and Haroun and Ellaithy (1985) provide additional guidelines on the dynamic analysis of pedestal-mounted tanks.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit
Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

CHAPTER 10—COMMENTARY REFERENCES

Committee documents are listed first by document number and year of publication followed by authored documents listed alphabetically.

American Concrete Institute (ACI)

ACI 350-20—Code Requirements for Environmental Engineering Concrete Structures (ACI 350-20) and Commentary

ACI 371R-16—Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks

American Society of Civil Engineers

ASCE/SEI 7-16—Minimum Design Loads and Associated Criteria for Buildings and Other Structures

American Water Works Association (AWWA)

ANSI/AWWA D110-13 (R18)—Wire- and Strand-Wound, Circular, Prestress Concrete Water Tanks

ANSI/AWWA D115-17—Tendon-Prestressed Concrete Water Tanks

International Code Council (ICC)

IBC-2003—International Building Code

IBC-2012—International Building Code

International Conference of Building Officials

UBC-1997—Uniform Building Code

European Committee for Standardization (CEN)

EN 1998-4(2006)—Eurocode 8

Federal Emergency Management Agency (FEMA)

FEMA 450-2:2003—NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures: Commentary

FEMA P-750:2009—NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

Standards New Zealand

NZS 3106:1986—Design of Concrete Structures for the Storage of Liquids

AIJ, 2010, "Design Recommendations for Storage Tanks and Their Supports with an Emphasis on Seismic Design," Architectural Institute of Japan, Tokyo, Japan, 179 pp.

ASCE, 1981, "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," Committee on Gas and Liquid Fuel Lifelines of the Technical Council on Lifeline Earthquake Engineering, Section 7, American Society of Civil Engineers, Reston, VA, 473 pp.

ASCE, 1984, *Fluid/Structure Interaction During Seismic Excitation*, Committee on Seismic Analysis American Society of Civil Engineers, Reston, VA, 74 pp.

Bandyopadhyay, K.; Cornell, A.; Costantino, C.; Kennedy, R.; Miller, C.; and Veletsos, A., 1993, "Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances," Brookhaven National Laboratory, Associated Universities, Inc., National Technical Information Service, Jan.

Bertero, V. V., 1995, "Energy-Based Design Approach," *Performance-Based Seismic Engineering of Buildings*, SEAOC, Apr., pp. D-1 to D-12.

Douglass, S. L.; Chen, Q. J.; and Olsen, J. M., 2006, "Wave Forces On Bridge Decks," Coastal Transportation Engineering Research & Education Center Department of Civil Engineering, University of South Alabama, Mobile, AL, June.

Goudarzi, M. A.; Sabbagh-Yazdi, S. R.; and Marx, W., 2010, "Seismic Analysis of Hydrodynamic Sloshing Force on Storage Tank Roofs," *Earthquake Spectra*, V. 26, No. 1, pp. 131-152. doi: 10.1193/1.3283902

Haroun, M. A., 1984, "Stress Analysis of Rectangular Walls Under Seismically Induced Hydrodynamic Loads," *Bulletin of the Seismological Society of America*, V. 74, No. 3, pp. 1031-1041.

Haroun, M. A., and Ellaithy, H. M., 1985, "Seismically Induced Fluid Forces on Elevated Tanks," *Journal of Technical Topics in Civil Engineering*, V. 3, No. 1, 1985, pp. 1-15.

Housner, G. W., 1956, "Limit Design of Structures to Resist Earthquakes," *Proceedings, World Conference on Earthquake Engineering,* University of California, Berkley, pp. 5-1 to 5-13.

Housner, G. W., 1957, "Dynamic Pressure on Accelerated Fluid Containers," *Bulletin of the Seismological Society of America*, V. 47, No. 1, 1957, pp. 15-37.

Housner, G. W., 1963a, "Dynamic Pressure on Fluid Containers," *Technical Information Document (TID) 7024*, Chapter 6, and Appendix F, U.S. Atomic Energy Commission.

Housner, G. W., 1963b, "The Dynamic Behavior of Water Tanks," *Bulletin of the Seismological Society of America*, V. 53, No. 2, pp. 381-387.

Isaacson, M., 2010, "Earthquake-Induced Hydrodynamic Forces on Reservoir Roofs," *Canadian Journal of Civil Engineering*, V. 37, No. 8, pp. 1107-1115. doi: 10.1139/L10-049

John A. Blume & Associates, 1958, "Report of Testing Program on Earthquake Cable Detail for the Preload Company."

Kobayashi, N., 1980, "Impulsive Pressure Acting on the Tank Roofs Caused by Sloshing Liquid," Proceedings of 7th World Conference on Earthquake Engineering, Istanbul, Turkey, pp. 315-322.

Malhotra, P., 2005, "Sloshing Loads in Liquid-Storage Tanks with Insufficient Freeboard," *Earthquake Spectra*, V. 21, No. 4, pp. 1185-1192. doi: 10.1193/1.2085188

Medearis, K., and Young, D. H., 1964, "Energy Absorption of Structures Under Cyclic Loading," *Journal of the Structural Division*, V. 90, pp. 61-89.

Newmark, N. M., and Hall, W. J., 1982, *Earthquake Spectra and Design*, Earthquake Engineering Research Institute Monograph, 103 pp.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Courtesy Subscription Account, Licensed to Sivaraju, Muralidhar
for Tuesday 11/29/2022 21:32:25 MST

Encuentra más documentos en www.udocz.com

NSF, 1981, "Earthquake Design Criteria for Water Supply & Wastewater Systems," *National Science Foundation Report* NSF/CE52-81079, Sept.

Scarlat, A. S., 1997, "Design of Soft Stories—A Simplified Energy Approach," *Earthquake Spectra*, V. 13, No. 2, pp. 305-315. doi: 10.1193/1.1585947

Tavakkoli, I.; Kianoush, M. R.; and Ghaemmaghami, A. R., 2012, "Effect of Three-Dimensional Geometry on the Sloshing Behavior of Rectangular Concrete Tanks," *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Portugal, Oct.

Uang, C. M., and Bertero, V. V., 1988, "Use of Energy as a Design Criterion in Earthquake-Resistant Design," *EERC Report No. UCB/EERC-88*, Nov., 57 pp.

Veletsos, S. A., and Shivakumar, P., 1997, "Dynamic Response of Tanks Containing Liquids or Solids," *Computer Analysis and Design of Earthquake-Resistant Structures*, D. E. Beskos and S. A. Anagnostopoulos, eds., Computational Mechanics Publications, Earthquake Engineering Series.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Encuentra más documentos en www.udocz.com

APPENDIX A—DESIGN METHOD

A.1—General outline of design method

In the absence of a more rigorous method of analysis, the general procedures outlined that follow may be used to apply the provisions of Chapters 1 through 9.

Basic seismic design parameters:

1. Establish the design depth of the stored liquid H_L, the wall height H_w, and the tank length or diameter, L or D, respectively;

2. From the applicable seismic ground motion map of ASCE/SEI 7-16 Chapter 22, obtain the mapped maximum considered earthquake spectral response accelerations at short periods and at 1 second (S_S and S_1, respectively). After selecting the site classification from ASCE/SEI 7-16 Table 20.3-1, obtain coefficients F_a and F_v using ASCE/SEI 7-16 Tables 11.4-1 and 11.4-2, and calculate S_{DS} and S_{D1} using Eq. (9-35) and (9-36);

3. Select an importance factor I from Table 4.1.1a;

4. Select the factors R_i and R_c from Table 4.1.1b for the type of structure being investigated;

Tank dynamic properties:

5. Calculate the weight of the tank wall (shell) W_w, roof W_r, and the stored liquid W_L. Also, compute the effective mass coefficient ε;

6. Calculate the effective weight of the impulsive component of the stored liquid W_i, and the convective component W_c using Fig. 9.2.1 for rectangular tanks or Fig. 9.3.1 for circular tanks;

7. Calculate the heights h_w, h_r, h_i, and h_c (EBP) and $h_i'$and h_c' (IBP) to the center of gravity of the tank wall, roof, impulsive component, and convective component, respectively (Fig. 9.2.2, 9.2.3, 9.3.2, and 9.3.3, or Sections 9.2 and 9.3);

8. Calculate the combined natural frequency of vibration ω_i of the containment structure and the impulsive component of the stored liquid (Eq. (9.2.4a) for rectangular tanks or Eq. (9.3.4a) for circular tank Types 2.1 and 2.2). The impulsive mode will generally fall into the rigid range of the response spectra; that is, the constant spectral acceleration region of the design response spectrum in Fig. R9.4.1, for common sizes of concrete tanks. Thus, if the maximum value of C_i is used (S_{DS}), calculation of the natural frequency and natural period is not required;

9. Calculate the frequency of the vibration ω_c of the convective component of the stored liquid (Eq. (9.2.4d) for rectangular tanks or Eq. (9.3.4f) for circular);

10. Using the frequency values determined in Steps 8 and 9, calculate the corresponding natural periods of vibration T_i and T_c (Eq. (9.2.4c) and (9.2.4f) for rectangular tanks, or Eq. (9.3.4c), (9.3.4d), and (9.3.4h) for circular tanks);

11. Based on the natural periods determined in Step 10 and the design spectral response acceleration values derived in Step 2, calculate the corresponding seismic response coefficients C_i and C_c (Eq. (9.4.1b), (9.4.1c), (9.4.2b), and (9.4.3a)). Note: Where a site-specific response spectrum is constructed in accordance with Section 4.2.1, C_i and C_c are determined in accordance with Sections 9.5 and R9.5;

Freeboard:

12. Where required, calculate the maximum vertical displacement of liquid surface (wave height) in accordance with Chapter 7. Adjust the wall height if required to meet freeboard requirements;

Base shear and overturning moments:

13. Compute the dynamic lateral forces (Eq. (4.1a) to (4.1d)) and total base shear V (Eq. (4.1e));

14. Calculate the bending and overturning moments (Eq. (4.1.3e) and (4.1.3h));

Vertical acceleration:

15. Compute the vertical amplification factor C_t in accordance with Section 9.4.3;

16. Calculate the hydrodynamic pressure p_{vy} (Eq. (4.1.4.2a));

Pressure distribution:

17. Compute the vertical distribution of the force components in accordance with Chapter 5;

Stresses:

18. In rectangular tanks, calculate the stresses in the wall due to the impulsive and convective pressures, depending on the structural system considered (Section 6.1) and the stresses associated with the increase in effective fluid density due to the vertical acceleration. In circular tanks, calculate the hoop stresses due to the impulsive and convective pressures and due to the vertical acceleration (Section 6.2); and

19. Calculate the overall bending stresses due to the overturning moments (from Step 14). Downward pressures on the neoprene bearing pads of free base circular tanks caused by overturning moments should be considered. If uplift develops on the heel side, then anchor cables must be provided.

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
American Concrete Institute Copyrighted Materials - Terms and Conditions - User=Sivaraju, Muralidhar
Wednesday, June 22, 2022 21:32:25 MST

Encuentra más documentos en www.udocz.com

--`,,```,,,````,``,,`````,,--`,,,,`,`,,,---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
lhs-markit-ihs-2103002, User=Sivaraju, Muralidhar
Not for Resale, 01/16/2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Not for Resale, 01/16/2022 21:33:25 MST

Encuentra más documentos en www.udocz.com

--`,,```,,,`,,`.`````,`,,.,,`````,,.-`-`,,,,`,`,`,,`---

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
Not for Resale, 01/16/2022 21:33:25 MST
Encuentra más documentos en www.udocz.com

American Concrete Institute
Always advancing

As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains "to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge." In keeping with this purpose, ACI supports the following activities:

- Technical committees that produce consensus reports, guides, specifications, and codes.
- Spring and fall conventions to facilitate the work of its committees.
- Educational seminars that disseminate reliable information on concrete.
- Certification programs for personnel employed within the concrete industry.
- Student programs such as scholarships, internships, and competitions.
- Sponsoring and co-sponsoring international conferences and symposia.
- Formal coordination with several international concrete related societies.
- Periodicals: the ACI Structural Journal, Materials Journal, and Concrete International.

Benefits of membership include a subscription to Concrete International and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level to discuss and share concrete knowledge and fellowship.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

--`,,`,`,`,,`,,,

American Concrete Institute
Always advancing

38800 Country Club Drive
Farmington Hills, MI 48331 USA
+1.248.848.3700
www.concrete.org

The American Concrete Institute (ACI) is a leading authority and resource worldwide for the development and distribution of consensus-based standards and technical resources, educational programs, and certifications for individuals and organizations involved in concrete design, construction, and materials, who share a commitment to pursuing the best use of concrete.

Individuals interested in the activities of ACI are encouraged to explore the ACI website for membership opportunities, committee activities, and a wide variety of concrete resources. As a volunteer member-driven organization, ACI invites partnerships and welcomes all concrete professionals who wish to be part of a respected, connected, social group that provides an opportunity for professional growth, networking and enjoyment.

--`,,```,,,````,,`,,,,,,,,,,,,-`-`,,`,,`,`,,`---

9 781641 951616

Copyright American Concrete Institute
Provided by IHS Markit under license with ACI
No reproduction or networking permitted without license from IHS Markit

Descargado por jorge corzo (jorge.corzo@pmicsa.com.mx)
...1030002, User=Sivaraju, Muralidhar
Not for Resale, 01/16/2022 21:33:25 MST

Encuentra más documentos en www.udocz.com